Bugging the Human Diet:
An interdisciplinary study on insects as future foods

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Abstract

Bugging the Human Diet: An interdisciplinary study on insects as future foods

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As food supply practices must adapt to the reality of limited natural resources, we must find alternative solutions to meet the dietary needs of a growing world population. This dissertation reports on the viability of edible insects as a solution to globally improve food security. Compared to conventional livestock, insect production requires less feed, water, and space while generating less pollution and waste. Moreover, circular insect farming methods can allow the reintroduction into the food chain of various types of clean and traceable organic residues in order to produce sustainable animal proteins within cities, therefore improving food sovereignty at the local scale. However, the general aversion for edible insects represents a major barrier that must be alleviated.

This dissertation identifies strategies to efficiently and sustainably introduce insect farming and consumption at the city scale. The introductory chapter of this thesis provides the rationale behind my research, framing its research area and explaining its key objectives. The second chapter is oriented towards consumer behavior as it focuses on the challenges related to marketing insect food products, paying particular attention to the motivations driving food choices. The third chapter exposes the results of both a national survey I developed aiming to assess the perceptions and attitudes of Canadians towards entomophagy (i.e. insect consumption) as well as insect tastings I organized in order to develop a better understanding of Quebeckers' preferences for edible insect products. The fourth chapter exposes an action research project I led involving high school students delving on exposure and familiarization with edible insects as an avenue to positively change their perception towards entomophagy. The fifth chapter discusses how following industrial ecology principles in insect farms can allow to lower both production costs and environmental impacts. Finally, the concluding chapter holistically reflects on entomophagy and entotechnologies (i.e. insect farming practices) as sustainable solutions to reduce the ecological impacts linked to the production and consumption of animal proteins – tackling food waste and thus reducing the carbon footprint associated to the management of rapidly decomposable organic materials.

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The research project allowing for almost 700 high school students to engage with insect farming was made possible by *Les Amis de l'Insectarium de Montréal* (Noémie La Rue Lapierre) as well as the *Collège Durocher St-Lambert* and its participating teachers from the science and technology program (Chantal Pelletier, Mylaine Boileau, and Sylvie Lemay). The initial 30-minute presentations were delivered by the *David Suzuki Foundation* while the insect farms used for this project were provided by insect farming consulting services *Insecto* (cricket farms designed by Benoît Daoust) and *TriCycle* (mealworm farms designed by me).

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Finally, thank you to my beloved parents without whom none of these exciting and enriching projects would have never been possible. The unconditional love and unlimited support they have always surrounded me with allowed me to pursue my most ambitious (though sometimes preposterous) dreams. May I have the same patience and care to one day infuse a human being with childhood memories as sweet as the ones I will forever cherish.

Contribution of authors

Contributing authors will be mentioned in the forewords between each chapter when applicable.

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Abbreviations and acronyms

ANAC: Animal Nutrition Association of Canada
CEGEP: Collège d'Enseignement Général et Professionnel
CMM: Communauté Métropolitaine de Montréal
EDW: Equivalent dry weight
EFSA: European Food Safety Authority
FAO: Food and Agriculture Organization
MAPAQ: Ministère de l'Agriculture, des Pêcheries, et de l'Alimentation du Québec
MDDELCC: Ministère de l'Environnement et de la Lutte contre les Changements Climatiques
OECD: Organisation de Coopération et de Développement Économique
OWD: Our World in Data
PIP: Processed insect products
SMS: Spent mycelium substrate
USDA: United States Department of Agriculture.
USEPA: United States Environmental Protection Agency

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Preamble

"The destiny of nations depends on the manner in which they feed themselves"
Brillat-Savarin (1826)

After graduating from a computer science program in high school and studying police technology in college (*CEGEP*), few would have guessed – myself included – that I would one day be writing a doctoral thesis reflecting on the relevance of insects in human diets. Judging from my academic path, I might be portrayed as having a rather confused soul. A true *Millennial*, after all. But I can't blame my generation though. Learning to develop a sense of critical reflection at the turn of the millennium has come with its share of anxieties. As the arrival of the Internet and smartphones were shining a light on the challenges raised by climate change, biodiversity loss, social injustices, economic instability, and so on, I remember feeling an overly heavy sense of burden. The future didn't seem so bright anymore and patrolling the city streets to solve micro crises suddenly didn't feel as empowering as it did when I was a kid. After three years of police training, I allowed myself some time to travel the world, perhaps hoping for a revelation regarding my career options.

Although I wouldn't exactly describe it as an epiphany – backpacking in Australia had rather familiarized me with the joys of social drinking and scuba diving – I decided at my return in Canada to complete my university application in environmental geography at *Université de Montréal*. It would allow me to keep exploring the world, this time through the lens of textbooks. What geography had to offer went beyond maps and atlases, which was all I had learned from it in high school. Not only has it brought me to understand the biological, physical, and chemical processes that shape our planet, but it also familiarized me with the wicked challenges of globalization, demographic growth, and climate change. My interest at that time was rather oriented towards physical geography, as I was developing an obsession for glaciers. But one professor – through his devotion, his passion, and his oratory skills – has developed my curiosity for the world of agriculture, which quickly turned into passion.

Professor de Koninck's long career was clearly coming to an end (the profound sighs he couldn't hold inside in front of confused students were betraying clear signs of exhaustion). But I pushed my luck and asked if he would oversee my Master's thesis. His commitment for geography was such that, although he was now starting his 8th decade on Earth, Rodolphe kindly accepted. I would become the last student to benefit from his immense body of experience and knowledge. However, the topic of my thesis was rather imposed: I would work on remittances (i.e. money transfers) as part of the resilience strategies developed by Javanese peasants to cope with the loss of opportunities in the food production sector following the agrarian transition in Indonesia. I quickly agreed to delve into that topic, especially as his research Chair would allow me to spend a few months on Java first learning *bahasa Indonesia* and then travelling from one village to another interviewing members of rural communities and government officials, with the precious help of a local facilitator.

The environmental, social, and economic impacts of the agrarian transition that took place in Southeast Asia – one of the world's main cradles of agriculture – are clear manifestations of the unsustainability of our globalized food production system. Having been exposed to these wide-ranging issues, it was hard to move on with my life without understanding how better food supply practices could be envisioned. Only assessing and reporting on the magnitude of the problem was quite depressing and didn't seem to provide any hope for a positive change. If I were to keep working on these issues, I wanted my energy to be devoted towards avenues to support a healthier and more diversified food production system.

The everyday decisions we make as food consumers either contribute to change or to consolidate the prevailing agri-food system. Food choices are thus a series of political statements: you either choose to care about the situation or to ignore and encourage the *status quo*. This simple thought felt empowering. Influencing consumers' food habits could therefore have a significant impact on accelerating the transition towards more sustainable food production practices. At that time, I had stumbled upon a fascinating topic that provided hope and seemed to be gaining significant recognition in the scientific community. Edible insects can be produced with much fewer resources than those required by conventional livestock – given that sustainable farming practices are supported, that is without falling into the trap of replicating the dominant oligopoly-controlled monocultures that have come to commonly characterize the agricultural Industry (see Chapters 1 and 6). If only we could get more people to eat bugs rather than conventional meat. But this raises significant challenges, particularly due to deeply rooted psychological and cultural barriers that must be alleviated (see Chapter 2). If we can find strategies to overcome such obstacles though, these could be applied to a wide array of unconventional though sustainable food products – many of which are already available on the market but simply fail to reach people's busy minds and conservative stomachs.

Delving into the world of edible insects thus implied to adequately assess their nutritional benefits and sustainable farming practices, and even more challengingly to properly understand the evolution of human food choices and their drivers. As no university program on edible insect farming and consumption was yet in place, I had no choice but to create my own curriculum. Concordia University was making it possible for graduate students interested in innovative interdisciplinary studies to send a proposal that clearly explains their rationale. I was asked to identify three disciplines, each of which along with a professor that would accept to supervise my research. Two disciplines appeared quite essential to me: the sociology of food and food marketing. I was lucky enough to quickly find two highly knowledgeable and motivated professors that were confident enough in my approach to sign in – Satoshi and Jordan, to whom I express my most sincere and profound gratitude for believing in my approach, for constantly sharing new ideas, and for supporting me throughout this rather unconventional five-year path.

If graduating from a French program in geography and delving into food sociology and marketing for my doctoral research was quite a stretch, incorporating a third discipline to my thesis proposal could be considered an Olympic long jump. As a geographer and traveller, I've come to develop a deep curiosity towards my surrounding environment. My interest in still photography – allowing me to share my overseas experiences with friends and relatives – expanded as I began to explore the world of sound and moving images through the production of music videos. It pushed me to develop many skills, such as programming, filming, and editing.

As a student, I had often felt the boundaries of science in the process of captivatingly transmitting information to the public. In the midst of my Master's path, I was searching for alternative ways to disseminate my research findings. I felt challenged the process of sharing academic research through emergent media rather than relying on traditional academic papers, which often seem unappealing and hardly accessible to the general public. I thus simultaneously started a part-time major in Concordia's Intermedia and Cyberarts (*IMCA*) program – where I discovered the infinite possibilities of visual programming languages in order to create interactive environments. When I was writing my doctoral application, I was deeply appealed by the idea of integrating a research-creation component that would allow me to merge both my passions for new media and food studies. I thus reached out to a few professors in communication studies. Some of them were curious enough to accept to meet with me, and Liz even accepted to join my supervisory committee.

Halfway through the first year of my doctoral program, I was determined to launch a participative insect farm on campus. It would use food waste generated on campus to feed crickets and would generate organic fertilizer for community plant growers (using insect feces). I wanted to develop educational activities allowing for students to get familiarized with edible insect farming and consumption while attempting to assess its effectiveness in alleviating psychological barriers towards entomophagy (i.e. edible insect consumption). I saw insects as holding a great pedagogical potential and thought they could help diversify and democratize urban agriculture. I thus formed a working group at the *Concordia Food Coalition* (*Chirps for Thought*; see Appendix A for project description) to help gather volunteers that would support the organization of workshops and other activities. I also found other working groups on campus to partner with (e.g. brewers, cafés, vermicomposters, etc.) and successfully secured funding through the *Sustainability Action Fund* (see full project description in Appendix B), the *Concordia Council on Student Life*, as well as the *Integrated Residual Materials Management Program*. Following its construction, the farm would be financially self-sufficient: it would generate revenues by selling insects in farmers' markets and even through their incorporation in meals sold on campus! But my project faced an unexpected challenge: as small as it could be, there just didn't seem to be any place within the university walls where I could set up this farm. Security motives were alleged, as authorities were frightened by the impacts of a possible insect infestation.

At that time, I was starting a *Mitacs*-funded internship with the urban beekeeping company *Alvéole*, which was founded a few years earlier by a few friends of mine. This project was composed of three internship units, each spreading over a four-month period (see Appendix C for complete description). First, I attempted to implement a cricket farm that would allow *Alvéole* to diversify their revenues derived from selling insect products (from only honey to edible insects and fertilizer). The second internship unit was focused on designing compact insect farms[1] that the company could sell out to people or organizations interested in rearing their own insect colony. Finally, my last objective was to develop pedagogical material involving edible insects so that *Alvéole* could widen the scope of the insect farming activities they were already offering for schools and other institutions. In partnership with *Les Amis de l'Insectarium de Montréal*, it allowed me to complete a research where I assessed the effectiveness of familiarization with edible insects on youngster's perception and attitude towards entomophagy (see Chapter 4).

During the second year of my program and in my attempts to find a professor in biology that would support my on-campus insect farm project by providing guidance when needed, I was referred to a previous Concordia student who had successfully set-up a composting system on campus a few years earlier. Having finished her doctoral studies in biology and now working for a large environmental NGO, she promptly invited me for a meeting at her downtown office. After

[1] www.bit.do/hakuna

explaining the research project that I had in mind, she couldn't hide her excitement as she mentioned being about to pursue a postdoc on edible insects. Although her efforts in reaching out with old contacts she had at *Concordia University* to help me secure a space turned out unsuccessful, she did manage to find some space in a laboratory at *UQÀM* (*Université du Québec à Montréal*) where we could initiate insect feeding experiments using spent mycelium from an urban mushroom farm (*Blanc de Gris*).

In order to keep working on these experiments, and in an effort to gather funding that would allow me to keep following my research (my first application for governmental doctoral funding had been rejected), I applied for another funded internship opportunity (*BSMP: scholarship for an internship in a practice environment*, from the *Quebec Research Fund in Society and Culture*). A few months later, the project was accepted. I was thus undertaking a six-month internship at the Montreal Biodome, the largest natural science museum in Canada. I was going to assess the feasibility of upscaling our initial mealworm feeding experiments using by-products in the hope of implementing a mealworm colony inside the museum that could potentially allow to feed birds, monkeys, fishes, and other insect-feeding animals it housed (see Appendix D for project description). Although using insects as animal feed wasn't exactly in line with my initial doctoral research objectives, a local insect diet would at least compensate the rather embarrassing carbon footprint linked to the diet of these captive species originating from ecosystems spreading all over the world. Animals turned out to be much less picky than humans when it came to insect eating.

It soon became obvious that my current research projects were grasping too much of my time and attention to investigate new media components. As biological experiments were starting to play a crucial role in my research, I thus asked my new colleague – who had recently started her postdoc at *Université Laval* – if she would agree to join my supervisory committee. I remember feeling a deep relief when she enthusiastically accepted: I had finally identified the third field of study that would constitute my interdisciplinary thesis. While completing my internship at the Montreal Biodome, I received a second refusal letter regarding my governmental doctoral funding application. From the information I received, interdisciplinary research projects were often found very hard to rank by reviewers as they had to read wide ranging applications and compare projects as diverse as immigrant linguistics, Chinese puppets, and edible insects. Research proposals that were at the junction of the social and natural sciences were even trickier, as applicants still had to choose at which of these two distinct funding agencies they would send their application (FRQSC or FRQNT at the provincial level, SSHRC or NSERC at the federal level).

A few months later, I received an email from *Mitacs* (the agency that had funded my previous internships with *Alvéole*) informing me that a new program allowed graduate students to benefit from paid internships when launching their own enterprise. According to my experience so far, funding through internships seemed better suited for the type of innovative, interdisciplinary, and action-based research I was undertaking. A few months earlier – as I was starting to lose hope on my chances to launch a participatory mealworm farm on campus as a way to engage in action research – I had suggested to my colleague (and recently doctoral co-supervisor) that perhaps we should launch our own mealworm farm, focused on organic waste upcycling. It would allow us to keep on carrying feeding experiments, this time in our own facilities so we wouldn't have to rely on other organizations. We would be able to better balance insect diets by integrating different types of organic by-products, have a better control on environmental parameters (mainly humidity and temperature), and assess how upscaling our experiments in a real-world farming environment could affect its outcomes (insect rearing densities can have a significant impact on their efficiency to convert feed into body mass). Moreover, I wanted to delve further into the fertilizing benefits of insect frass (i.e. droppings and shed skins) in order to help picture a truly circular urban food production network. Launching my own start-up would also allow me to engage in action research on marketing, assess the efficiency of different edible insect marketing strategies in a real business environment. Combining theory with action would make it possible to validate my research assumptions and thus come up with stronger hypotheses. This academic spin-off enterprise was also a great way to develop applied skills in order to facilitate my integration in the job market following the completion of my doctoral research.

My colleague and co-supervisor proposed that we should integrate her husband in the project. It first sounded like a good idea, as his addition would provide us with complementary skills (he was himself pursuing a Master's in environmental engineering). We thus went forward and submitted a joint *Mitacs* application to the *Entrepreneur Accelerate* program, which would allow us to complete a total of 15 four-month internship units – five of which I would be undertaking myself (see Appendix E for project and internships description). By the time our application got reviewed by a scientific committee and accepted by the funding agency, we had already secured a space to launch our farm. As I had gradually made my path into the world of urban agriculture (although my experience in this field was at first pretty much limited to the world of insect farming), I made interesting encounters in this remarkably tight community. I had even been recruited to teach urban environment and sustainable development for a new technical certificate that was launched at the *CEGEP de Victoriaville*.

In line with this contract, I came in touch with the *Laboratoire sur l'Agriculture Urbaine (AU/LAB)* – a highly reputed working group at *UQÀM* leading research, innovation, and intervention in the world of urban agriculture – who was planning on launching an urban agriculture cooperative in Montreral. It would allow a few start-ups to come together and share common infrastructures, thus providing them with considerable benefits, including access to a cheaper rent. I quickly grasped this opportunity. Our insect farming company thus became part of the five founding members of *La Centrale Agricole: Coopérative de solidarité de producteurs urbains*, and I was elected the representative of our company on the coop's governing board. I felt an immense faith in the project as we rapidly secured a space as well as financial and political support to start renovating an old commercial space in Montreal's highly industrial *District Central* area, where changes in the municipal zoning were obtained so that we could carry agricultural activities.

This quickly became a pretty ambitious project: roughly a year after finishing the initial phase of the renovation works, the coop was now housing more than a dozen different urban agriculture organizations (producers, processors, and distributors)[2], and we kept on receiving new applications. We hired a coordinator and part of his mandate was to support the realization of industrial synergies where different organizations amongst the coop would come together to generate innovative partnerships. Opportunities were tremendous for our insect farm (see Chapter 5) – for which I had by then come up with the name *TriCycle* (evoking circularity as well as the process of learning a new efficient way to move forward).

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2 www.baronmag.com/2020/01/montreal-pionniere-en-agriculture-urbaine-avec-la-centrale-agricole/

I was stoked by all these projects that were suddenly taking place. My objective when undertaking doctoral studies had always been to achieve applied research that could truly generate positive outcomes in the investigation and promotion of sustainable food production systems. Of course, stepping off the beaten path came with its important share of uncertainties and challenges – most often completely unexpected. But I was well aware of that and my excitement and motivation allowed me to overcome most of these obstacles. One of the main difficulties was time management: launching both a coop and a company simultaneously required me to get familiarized with many aspects of business management, while completing my research internships and working on my doctoral thesis. And managing an insect farm is very different from manufacturing clothes or bicycles; insects are living creatures that require constant care. Needless to say, my social life was put on hold for quite a while.

Good news kept on coming for TriCycle, as we had managed to obtain significant governmental funding allowing us to acquire specialized equipment and were quickly gaining credibility in the sector – namely through the implementation of a technological showcase supported by the *MAPAQ* (Quebec's Ministry of Agriculture, Fisheries and Food) to promote circular insect farming practices. We were also gaining important media coverage[3] and even won a start-up contest (*Mouvement Novae*[4]). The two business incubators (*District 3* and *L'Esplanade*) that supported the company were providing great guidance, though they also required me to participate in time-consuming series of bootcamps, workshops, and coaching sessions.

In the midst of Winter 2020, we finally felt confident enough to hire employees who would start taking over insect farming and processing operations. As our insect population was reaching full capacity, we were going to start harvesting them on a regular basis. At first, I felt relieved as I would need to spend less time taking care of our insect colony. However, I quickly realized that my role of commercialization and marketing manager was now going to require tremendous efforts (edible insects and frass also don't sell as easily as t-shirts and bikes). However, I was thrilled to finally get the time to work on these aspects. I had recently published a scientific paper on edible insect marketing (Marquis et al., 2020) and there were a few ideas I wanted to experiment. But what came at that moment was quite unexpected: the COVID-19 virus which had started spreading into the country was significantly affecting our commercialization activities.

In order to develop appealing recipes that would gradually help overcome consumers' reluctance towards edible insects, the first clients we wanted to reach out to were restaurant chefs and owners. Unfortunately, restaurants were quickly being shut down as part of the first measures that the Quebec government decided to implement in order to control the epidemic. Moreover, it was

[3] www.ledevoir.com/societe/sante/559921/utiliser-nos-dechets-pour-nous-nourrir
www.lapresse.ca/actualites/environnement/2020-01-06/planete-bleue-idees-vertes-des-insectes-qui-carburent-au-compost
www.novae.ca/elever-des-insectes-pour-reduire-le-gaspillage/
www.globalgoodness.ca/se-nourrir-grace-aux-insectes/
www.salutbonjour.ca/2020/03/04/des-insectes-dans-notre-assiette
www.ici.radio-canada.ca/premiere/emissions/desautels-le-dimanche/segments/reportage/152521/economie-circulaire-pour-en-fini-avec-les-dechets-alexandre-touchette
www.ici.radio-canada.ca/premiere/emissions/les-annees-lumiere/segments/reportage/155054/concours-novae-insecte-jardin-plastique-developpement-durable-economie-verte

[4] www.novae.ca/tricycle-remporte-concours-mouvement-novae-2020/

becoming extremely hard to get our products into grocery stores, as managers and distributors were mainly preoccupied by their ability to ensure a continuous supply in basic and popular foodstuffs – which unfortunately insects were apparently not yet part of. Similarly, edible insect food processing companies were also suffering from a lack of demand for their products. Many found themselves in a precarious financial situation and had to slow down their operations. They definitely weren't looking for new suppliers.

As for insect frass, it was simply too early to expect important sales. The product was new on the market and we had to compete with well-implanted fertilizer companies that could sell their products for a fraction of our price (e.g. hen manure). As part of my *Mitacs* internship, I had just started plant growth experiments on the coop's green roof in order to better assess the benefits of insect frass. It would allow the company to identify key promotional arguments to help better sell our product (see Chapter 5). But results would only be compiled at the end of the growing season, while fertilizer sales are mainly focused in Spring.

The situation became preoccupying for our company. We had invested a lot of time, energy, and money to develop marketable products, but we were unable to generate sufficient revenues in sales to cover for our expenses. Due to my role in the organization, I personally felt a lot of pressure to quickly find new clients. Other than the few recurring clients we had managed to secure (mainly in the pet food industry), we thus attempted to rely on online sales. Although initiatives supporting a buy-local movement were increasing, demand for our products remained very limited. As our initial strategy didn't imply to rely so quickly on direct-to-consumer sales to generate revenues, we hadn't yet planned a solid marketing campaign. Convincing Quebeckers to eat insects was definitely not a breeze (see Chapter 3).

I now had to face another challenge raised by engaging in collaborative action research. Social relations between colleagues can get quite tumultuous, particularly when exhaustion and anxiety are starting to build up. In order to avoid a conflict of interest, I had to find a new supervisor that would take over my colleague's position on my committee. Rather than looking for a biology professor, I reached out to Alan – a geography professor at *Concordia University* devoting a specific interest into food studies – who kindly accepted to assume this role. After flirting with communication studies and biology, I thus decided to renew with geography.

Understanding the key biological aspects of insects had indisputably been essential in my academic journey so far. Engaging in insect feeding and plant growth experiments allowed me to better assess the feasibility of implanting circular insect farming methods. Although interdisciplinarity had always been a key motivation driving my research, I was coming to the realization that merging social and natural sciences research was perhaps too much of a stretch. Developing a proper understanding and a sense of critical reflection on the sociocultural aspect of insect consumption would require more focused efforts. This decision was also supported by an opportunity I had recently been offered following the completion of my thesis, namely to pursue postdoctoral research in this field by joining an international research group based in France.

In the weeks subsequent to this transition on my supervisory committee, I learned that my associates had taken the decision to dismiss me from my role of administrator as well as the commercialization and marketing manager for *TriCycle*, which also meant that I was going to lose my seat on the coop's Board of Governors. This decision had a devastating effect on me. I was going to have profound consequences not only on my professional sphere but also on my thesis. I now didn't have access to a bunch of data that I was planning to use for my research, and I was asked to avoid disclosing any business-related information that was now considered confidential. For instance, in the last chapter of my thesis – where I attempt to quantify the economic benefits of relying on diverse strategies derived from industrial ecology principles in order to lower insect production costs – I had to rely only on fictive numbers, while other key advantages could only be discussed partially and/or qualitatively.

Throughout these busy five years of my doctoral studies, I have thus been confronted with many challenges – theoretical, logistical, financial, and social – raised by undertaking innovative and interdisciplinary action research in the field of entomophagy and entotechnologies. Nonetheless, I'm happy that this rather unconventional path has allowed me to develop both investigative and marketable abilities in an innovative and quickly evolving field of knowledge. Since I started my research, I've assisted in: (1) the creation at *Université Laval* of a leadership Chair on edible insect education, production, and processing; (2) the organization in Quebec City of the international congress *Insects to Feed the World* (which was postponed to 2022 due to the COVID-19 pandemic); and (3) the creation of an association gathering local insect farmers and food processors to help better structure the local Industry (*Association des Éleveurs et Transformateurs d'Insectes du Québec*). There is no doubt that this sector is booming. With the considerable body of knowledge and skills I have acquired throughout these past five years, I believe I am now well equipped to join this burst and help propel the edible insect sector even further.

Structure of the thesis

In the following pages, I will present my manuscript-based thesis. It is a collection of six chapters, four of which are intended for publication in scientific journals and thus presented in an article format: a review of the current state of knowledge available in the scientific literature, followed by the presentation of its methodology, its results, a discussion section (sometimes merged with the results section), and a conclusion. Forewords provide expository transitions between each chapter, contextualizing the following content in order to ensure a smooth transition with the ideas presented in the previous section. It will also mention the specific journal to which each of those articles have been or will be submitted as well as the contribution of other authors when applicable. In addition to these four core chapters are introductory and concluding chapters.

The following chapter represents the general introduction of my thesis. It provides the rationale behind my research. Starting with a literature review in order to help frame its research area, it then presents the overall problem statement and exposes my research objectives, each of which will be dedicated a complete chapter.

Chapter 1: Introduction – Supporting healthy and sustainable human diets in a post-pandemic era

Critical changes needed in our food production system

The pandemic that has rapidly spread throughout the world in early 2020 has triggered radical changes in peoples' lives. Many have and are still suffering from it – whether economically, physically, and/or psychologically. However, the economic slowdown in many parts of the world has left us with more time for reflection and mindfulness. As characterized by the (virtual) conversations we have with our families, co-workers, and friends, most people can't spend a day without wondering how we got to this situation, how bad is it going to be, when is it going to resolve, and will our lives even ever get back to "normal". Health and safety measures have completely transformed our whole lifestyle, including aspects as manifold as when we sleep, whom we see, where we go, how we work, how we shop, and what we eat. The pandemic has highlighted both the resilient and vulnerable aspects of our food system to a point where more people are questioning how our food is produced and how it makes its way to our tables. Because at the end of the day, the agri-food industry is responding to consumer demand, the daily dietary choices we each make are responsible for dictating the sustainability and security of our food system.

If climate change had already raised our awareness towards the unsustainability of globalized food production and distribution systems, the COVID-19 crisis is now showing us that changes are inevitable, and they must unfold with a greater sense of urgency. The further food travels, the more its safety can be put at risk and the greater the population that is threatened. It is hard to narrow down to one single factor the reasons that have led us to a world epidemic. However, it is clear that the loss of natural habitats plays a crucial role in supporting the spread of viruses – including zoonoses, which can then be transmitted to humans. Deforestation causes animals (some of which carry viruses) to live in more densely animal populated areas. When their food gets scarce, they migrate into areas where they get in contact with other species which they previously didn't cohabit with. Consequently, these animals then become vectors of newly transmitted diseases (de Sadeleer & Godfroid, 2020). A virus can thereby slowly make its way through the animal kingdom until it finally reaches the top of the food chain – either contaminating humans directly or indirectly through the animals they commonly farm and consume.

Mainly due to the large cultivable areas required to grow animal feed, livestock farming is the main factor leading to deforestation. Almost 80% of all agricultural land is used for farming and feeding livestock, although these provide only 20% of the calories produced for human consumption (Alexander et al., 2016). Population growth and diet transitions are constantly increasing global demand towards animal proteins (Alexandratos & Bruisma, 2012). Indeed, people in the developing world are increasingly adopting westernized (and heavily carnivorous) eating patterns – especially urban dwellers, who are quickly growing in numbers. Meanwhile, climate change is causing agricultural yields to decline (d'Agostino & Schlenker, 2016) and is multiplying the emergence of infectious diseases (Heffernan, 2018). Hence, food supply and consumption practices must adapt to the reality of environmental constraints. Vegetarianism and pescatarianism (i.e. seafood consumption) are often promoted as reliable solutions. But are they really?

Confronted with the food safety, human health, and environmental hazards of meat consumption, the first solution that comes to mind is to simply cut meat from our diet. Veganism and vegetarianism are increasingly popular in Western (i.e. European-derived) countries – most often motivated by personal health, environmental, or ethical concerns. As vegetal proteins typically don't include all nine of the essential amino acids needed by the human body (St Jeor et al., 2001), a meatless diet should include a diversity of vegetables and grains – which can be more complicated for people who are allergic or intolerant to certain foodstuffs. Of course, feeding crops directly to humans rather than to livestock is more efficient (in terms feed conversion ratios, or FCRs, which will be explained below) and contributes to fewer greenhouse gas emissions (as it implies less transportation and as enteric fermentation causes important methane emissions). However, the prevailing agricultural practice of relying on intensive monocultures used to fit the sector's demand for high yielding, appealing, homogeneous, long-lasting, and stackable products comes with its share of problems. It requires the use of heavy machinery (responsible for killing many pain-feeling animals, see Fischer, 2016) as well as massive amounts of pesticides and fertilizer, which leads to soil depletion, watercourse eutrophication, biodegradation, and health problems (Filson, 2005). Not only are aquatic and soil organisms threatened by such health hazards, but also humans and all other living creatures amongst the food chain, as many of these chemicals are prone to bioaccumulation (Li, 2020). Moreover, as soils can't be cultivated all year long in many parts of the world, most of the foodstuff has to be carried on long distances, thus increasing pressure on the transportation sector, which is amongst the main causes of greenhouse gas emissions on the planet (OWD, 2020).

As they spend less energy moving and maintaining body temperature, aquatic animals are commonly believed to be more efficient than large terrestrial ones in terms of FRCs, meaning the efficiency with which their organism convert feed into body mass. As for humans, our FCR is estimated at roughly 3:1, comparable to that of pigs (Miller & Ullrey, 1987). But the reason it appears so low is because humans typically consume many energy-dense foods, such as animal products, who have already done most of the feed conversion work themselves. In order to have a proper understanding of the ecological impact of the human diet, we must also take into account the FCRs of the animals we eat, as well as that of the other animals they have themselves consumed. The higher a species is situated in the trophic food chain, the more it is dependent on the diets of the species below, who indirectly contribute to feeding them. The FCR of cattle is very high, with estimates ranging between 8:1 to 12:1 – and that is by live weight, although an important proportion of these animals is inedible (Smil, 2000). As for chickens – although their FCR is much lower – their inability to digest cellulose (plant materials that also can't be digested by humans) means that the proteins and carbohydrates they must be provided with are derived from farmed crops and animals that are directly competing with human food (Waltner-Toews, 2013).

The importance of FCRs when assessing the efficiency of human diets was already exposed almost a century ago by Clifford Cook Furnas, who wrote in his book entitled "*The next hundred years: The unfinished business of science*" (1936):

> *"Animals convert only a small portion of a plant's energy into humanly usable food. As food factories, animals are way down in the efficiency list (...). Good calves return 1 part in 12 of the food given to them but the best full grown beeves* [i.e. cows] *only about 1 part in 30."* (p.313)

In the following lines, Furnas predicted that such a poor FCR would cause milk to become a very expensive food staple in the next decade or so from then. Nowadays, as the resources required to meat production are put under pressure, its prices are constantly increasing (FAO, 2021).

Hence, FCRs fail to consider important factors, such as the edible portion of an animal, the nutritional quality of its meat, or the provenance and composition of its feed (Fry et al., 2018). Due to fisheries rapidly overexploiting wild fish stocks, aquaculture is now the fastest-growing food animal sector – it exceeds wild caught seafood (FAO, 2018) and even beef (USDA, 2020) in terms of human food supply. But intensive aquaculture isn't a more sustainable practice than overfishing. Ponds are often built on destroyed mangroves and, as farmed seafood are typically less efficient in retaining protein and calories, they require massive amounts of fishmeal (Fry et al, 2018). Despite a higher FCR on paper, their nutrient retention ratios are thus comparable to those of terrestrial farmed animals. They also heavily rely on antibiotics, which can leach into ecosystems and bioaccumulate into the human body (Nguyen et al., 2016).

According to the Malthusian Theory of Population (Malthus, 1872), an exponentially increasing world population – whose survival depends on linearly growing natural resources – is inevitably destined to famine, war, poverty, and eventually depopulation. The elements having so far saved us from this sad faith are first and foremost linked to the unexpected and substantial increases in agricultural productivity following the Green Revolution that took place during the second half of the 20th Century – having been achieved through the use of chemical inputs, hybrid seeds, heavy machinery, and irrigation. But as societies must now look for more remote places and more energy-intensive ways to supply their constantly increasing food needs, related economical, ecological, and social costs are increasing, thus decreasing the relative benefits generated by these resources.

In a system based on infinite growth, there comes a point at which the cost of extracting, processing, and transporting such resources is greater than the benefit they can generate. In order to keep supplying public and private demand to support demographic and economic growth, these costs have for a long time been externalized through subsidies, welfare, as well as environmental damage. But as humanity faces critical climate change issues, we now must find sustainable solutions allowing for better returns on investments. How can we sustainably, locally, and efficiently provide food allowing for growing populations to thrive? In his book entitled *"Food: The Key Concepts"* (2008), Warren Belasco concluded by identifying two distinct future scenarios for feeding the world's population:

> "*The technological fix, which looks to science to provide the solution to our future food needs; and the anthropological fix, which hopes to change our expectations and behaviors*."

I argue that a sustainable and holistic solution actually resides at the junction of both these scenarios.

Insects as an innovative source of alternative proteins

Edible insects have been portrayed by the Food and Agriculture Organization as a viable solution to global food insecurity – with more than 2,000 species of insects known to be edible for humans (van Huis at al., 2013). Like most animals, their body mass contains high levels of complete proteins: a well-balanced combination of each of the nine essential amino acids required for the human body to thrive (Raheem et al., 2019). Insects are typically rich in mono- and polyunsaturated as well as omega-3 fatty acids (Ghosh et al., 2017) and in a variety of minerals and vitamins such as zinc, iron, and magnesium (Rumpold & Schlüter, 2013). Moreover, simulated in vitro digestion experiments revealed that edible insects could modulate the microbiome composition, which may exert positive anti-inflammatory effects on the human gut flora (Young et al., 2020) – as it has recently been suggested for fungal metabolites (Mogilnicka & Ufnal, 2019).

Insects can be suitable for both animal feed and human food. They represent a sustainable alternative to conventional meat. In fact, we already inadvertently consume millions of fragments of insects yearly (mostly hidden amongst processed grain foods and vegetables), totaling about two pounds of insects per person yearly (Hill, 2013). As insects are biologically less close to humans than vertebrate animals, most viruses infecting insects are not pathogenic to humans or other vertebrates (EFSA, 2015) – with the exception of arboviruses (e.g. dengue, West Nile, Yellow fever), which are vectored by blood-feeding insects only (Dicke et al., 2020). Their cold-blooded metabolism renders them highly efficient food converters and their great reproductive rates can translate into outstanding productivity.

Bioconversion through insects can allow the reintroduction of food waste into the food chain in order to produce sustainable insect proteins (Hénault-Ethier et al., 2017). Organic waste management (6.2%) and agriculture (9.6%) are responsible for 15.8% of all greenhouse gas emissions in Quebec, with the main drivers being food waste and meat production (enteric fermentation and manure management) (MDDELCC, 2019). Insects' omnivorous diet is a smart solution to allow for the sustainable management of organic waste within cities (Cabrera et al, 2015) while simultaneously improving food security at the local scale (Rumpold & Langen, 2020).

Furthermore, insect frass (i.e. excreta and shed skins) can act as a soil fertilizer as it is rich in trace elements and organic matter – an important component to improve soil life, its structure, and its resistance to drought, while allowing to sequestrate carbon (Bot & Benites, 2005). Given the large amount of chitin it contains (originating from insects' shed skins), insect frass also has phytosanitary properties (antifungal and insect repellent) (Kombrink et al., 2011). Thus, in addition to accelerating plant growth, it could protect them from invasive insect attacks as well as some fungal diseases. In addition, frass can help plants resist stresses such as drought, floods and salinity (Poveda et al., 2019). The chitin it contains is also of great interest for many industrial sectors, such as pharmaceuticals, textiles, cosmetics, and biotech (Morin-Crini et al., 2019). Therefore, upcycling food waste through insects can allow for the establishment of a truly circular agri-food system, producing sustainable protein-rich foods and feeds, organic fertilizers to enhance crop framing, as well as by-products for a variety of industries.

However, another foodstuff that promised to save the world's food crisis failed its introduction in consumers' dietary corpus. Halfway through the 20th century – in an era characterized by significant industrial modernization – scientists strongly believed that algae could sustainably provide the world population with sufficient nutrients, as the scarcity of both labor force and new cultivable land was limiting agricultural expansion (Belasco, 1997). The merits of algae were thought to be manifold: they are almost entirely edible, they can feed on organic waste, and they can even be used as a resource for many industries (Milner, 1953). This is not without reminding us of insect-associated benefits. Although algae were thought to initially represent an expensive protein alternative, higher demand for food was also expected to trigger considerable increases in grain and meat prices. However, algae production came with underestimated processing costs, whereas the Green Revolution allowed to keep food prices relatively stable by achieving substantial increases in agricultural productivity (Belasco, 1997).

The 1950s were also characterized by the great commercial success of a plethora of engineered foods designed to increase convenience, either through fast food restaurants or home microwaved meals. Women massively entering the workforce since World War II, longer commuting hours, and the widespread accessibility of home refrigerators all contributed to lower the average time dedicated to home cooking (Patel, 2012). Hence, algae burgers weren't considered at that time such a hard concept to wrap consumers' minds around. However, the efforts it would take to seduce consumers were also misjudged. While public awareness and marketing campaigns have failed to reach mainstream consumers, algae's high prices have restricted their target to high-end gastronomic markets (with also a limited success).

Will edible insects be destined to a similar fate? Will a third green revolution (the second one consisting of genetically modified organisms) appear and induce an important paradigm switch? Perhaps, insects might be at the center of this upcoming green revolution, as urban vertical indoor farming might provide a technological fix to the food crisis. For the moment, indoor farming remains extremely cost- and energy-intensive. Hence, it is essential to identify candidates that can generate great nutritional benefits. Along with other alternative proteins such as jellyfish (Purcell, 2013) or cultured meat (Gaydhane et al., 2018), insects appear as interesting options for indoor farming, especially as they can generate valuable by-products.

Assessing barriers to adopting edible insects

Forced by increasing environmental constraints, the next food revolution will most likely imply radical changes at the consumer end. During World War II, when most of the domestic meat was monopolized to feed soldiers, marketing tactics focusing on patriotism have successfully raised consumption barriers for unconventional animal products, such as animal organs (Guthe & Mead, 1943). Will similar austerity measures – this time for the sake of environmental protection and global food security – allow for a dietary transition to occur?

In order for a successful sustainable switch in meat consumption habits to take place, marketers must focus on increasing consumers' desire for "*future foods*" – ones that are in line with contemporary preoccupations for tastiness, healthiness, sustainability, and social solidarity (Saitone & Sexton, 2017). They must also attempt to satisfy our curiosity and craving for a diversified set of flavors inspired by culinary habits from across the world (Agritecture, 2019). Edible insects represent an opportunity to develop marketers' adaptability to evolving food trends and preferences. But succeeding to this challenge implies to find the appropriate set of strategies in order to turn insects disgust into craving.

Radically new products that challenge traditional cognitive patterns, such as edible insects, are considered discontinuous innovations (Robertson, 1971). Strong psychological barriers are preventing consumers' willingness to adopt insects in their diet. In order for insects to be perceived as culturally edible and to reduce the aversions linked to danger and disgust (Rozin et al., 2008), strategies put forward must contribute to modifying individual and social mental representations. There are two distinct practice-based modes by which novel foods may be introduced: the *full spectrum mode*, in which a cuisine and the ingredients involved are being re-enacted in a new location, and the *single ingredient approach*, in which a new foodstuff is being incorporated into existing food practices by being positioned as a superior material as compared to feasible proximate alternatives (Hargreaves, 2011).

The successful implementation of a new culinary practice in the full spectrum mode requires three fundamental elements: the material (i.e. product widely available and affordable), the competence (i.e. preparation knowledge and culinary skills), and the meaning (i.e. social significance of its benefits) (Shove et al, 2012). Before these elements become solid enough to support the introduction of edible insects in North American cuisines, the *single ingredient approach* seems more appropriate. But this approach requires the adequate positioning (or "script") of edible insects on the market. Moreover, once strategically positioned, they will still have to adequately respond to consumers' criteria for this food category, such as appearance, taste, texture, price, and availability.

Due to their ecological and health benefits, edible insects have first been portrayed to Westerners as an alternative to conventional meat. Yet, sensorial aspects and convenience (including price and availability) of insects aren't in line with consumers' expectations for products in this category. Moreover, marketing arguments used to promote edible insects have been wide-ranging and often failed to be aligned with other similar products on the molecular scale (Sexton, 2018), which can confuse consumers. As discontinuous food innovations are indeed often hard to link to existing food categories, they typically require radical changes in consumption modes (Gallen et al., 2019). But meat represents a sensitive domain in which consumers' likings and aversions tend to be deeply rooted as compared to other food categories (Tucker, 2014). Moreover, questioning our protein production and consumption habits quickly triggers biopolitical discussions about the notion of good versus bad eating[5] (Sexton, 2018).

Edible insects' excessive prices represent a major obstacle to their regular consumption, both as human food and as animal feed. In order to avoid commercialization failures (as it had been the case with algae), economic barriers must be addressed. In the upcoming years, the popularization of edible insects is likely to trigger increased private investments allowing the achievement of economies of scale through the semi-automation of labor-intensive and time-consuming farming tasks, thus gradually increasing the affordability of edible insects on the market. As a faster solution, upcycling organic waste can lower insect farming costs, while selling insect frass can allow for insect farmers to diversify their revenue streams. Industrial symbiosis can also help in decreasing operational costs associated with insect production. With more affordable prices, edible insects might be more easily positioned on the food market as an alternative to conventional meat.

<u>Problem statement</u>

Environmental constraints require significant changes in food systems. My research aims to identify pathways to alleviate psychological and economic barriers to insect production and consumption. My dissertation aims to answer the following research question: How can we normalize entomophagy in Western countries? In order to holistically address this issue, my research delves into key consumer-level (psychological and sensorial) and producer-level (sustainability and price) barriers. Its key objectives are to: (1) identify efficient marketing strategies and tactics enabling to overcome consumers' reluctance towards edible insects; (2) understand local consumers' behaviors and preferences towards edible insects; (3) focus on youngsters in order to support greater social acceptance towards entomophagy; and (4) identify ways to lower edible insect prices in order to support their regular consumption. Therefore, my main research question can be divided into four sub-questions:

- Which effective marketing strategies can help better support entomophagy?

[5] On this aspect, taking a closer look at what represents arguably the only ingredient playing a more crucial role than meat in North American diets – water – can allow to draw an interesting parallel, since important drinking water shortages in many cities around the globe are forcing consumers towards drinking recycled water (see Appendix F).

- What are the specific behaviors and preferences of French Quebeckers towards insect products?
- Can familiarizing youngsters with edible insects contribute to the popularization of entomophagy?
- How can we build sustainable and competitive insect farms?

Fields of study

Delving in sociological, marketing, and urban geography spheres of knowledge, the theoretical framework of my research accounts for the complexity of consumers' paths to entomophagy adoption as well as the political ecology of food production systems, itself known to be an intricate system. Engaging in innovative interdisciplinary studies will enable me to propose new answers to the core questions of my investigation. By tapping into different fields and corpuses of knowledge and practices, my research lays the groundwork for the identification of efficient strategies to normalize insect consumption and increase the sustainability and profitability of insect farming in Western societies. It underlines the mechanisms allowing for the alteration of individual and social mental representations that inhibit the acceptance of discontinuous food innovations, while enriching the development of much needed knowledge on alternative food systems – building bridges between various disciplines to simultaneously tackle social, cultural and environmental issues. My dissertation assesses sociodemographic correlates of dietary habits in order to uncover key strategies leading to overcome the reluctance towards unfamiliar foods, while addressing sustainable farming practices focusing on circular economy to tackle the challenge of demographic growth, pollution, and food insecurity.

Oriented towards social and cultural transformation, my investigation involves practical research in action (Reason & Bradbury, 2013). Action research is a rigorous process of critical reflection and empirical problem-based investigation. As its goal in to create and share knowledge while achieving transformative change, it is often facilitated by the participation of one or more existing organization(s) (Riel, 2019). My research follows the five phases identified by Susman (1989) to be conducted within each action-based research cycle: (1) identifying a problem and collecting data for a more detailed diagnosis; (2) postulating several possible solutions and identifying an action plan to be implemented; (3) collecting, analyzing, and interpreting data on the results of the intervention; (4) evaluating how successful the action has been; and (5) reassessing the problem and potentially initiating another cycle.

First, I conducted a review of the existing literature on entomophagy and consumer behavior, paying particular attention to the elements driving food choices. I then developed a survey allowing me to assess the perceptions and attitudes of Canadians towards entomophagy, which I have paired with insect tastings in order to develop a better understanding of consumers' preferences for edible insect products. Next, I conducted action research involving high school students to assess the impact of exposure and familiarization with edible insects on their attitude towards entomophagy[6]. The last component of my research relates to the development of industrial ecology practices in insect farms in order to minimize production costs and to alleviate its environmental impact. In order to facilitate my action research approach, I partnered with many existing organizations and even started my own insect farming company. It namely allowed me to initiate a series of experiments aiming to feed mealworms using organic residues originating from food production

[6] www.lecourrierdusud.ca/elevage-de-grillons-college-durocher-de-saint-lambert-a-ferme/

and processing companies. I also carried out plant growth experiments to assess the fertilizing properties of insect droppings.

1. *Identifying marketing strategies to overcome reluctance*

Examining literature from both food consumer behavior and entomophagy spheres of knowledge allowed me to pinpoint critical consumer-level barriers to the adoption of edible insects in Western countries. I identified key strategies to overcome such obstacles and divided them into three different spheres influencing food habits: (1) the *foodstuff*, or food's ability to reach traditional and evolving consumer preferences; (2) the *foodie*, or consumer's degree of adventurousness and the relative importance he/she devotes to taste and reflection; and (3) the *foodscape*, or characteristics of food packaging in relation to its location within stores as well as its surrounding local food culture. Altogether, the assessment of these three marketing spheres allows for the better identification of key strategies to be used in order to reach a wide-ranging set of potential insect consumers.

2. *Assessing local consumers' acceptance and preferences for edible insect products*

Effectively promoting edible insect foods requires a regionalized understanding of local consumers' attitudes and perceptions. I launched in 2017 a national survey aiming to assess Canadians' preferences for edible insect products and the main barriers preventing their mainstream adoption. As it was conducted roughly two to four years following another survey for which I had also contributed to the results' interpretation (Hénault-Ethier et al., 2020), it also attempts to assess the evolution of entomophagy acceptance and practice amongst French Quebeckers. In order to draw complementary conclusions, case studies have been led involving consumer tastings of four insect-based products. This naturalistic approach is typically used by food processing companies and known in the industry as a "food story" where consumers are invited to articulate their impressions, preferences, disappointments, and obstacles starting from a product and a concrete experience. It allows the better understanding of the barriers to trying and adopting insect products. It aims to better identify current challenges and barriers preventing entomophagy while feeding reflections contributing to a better penetration of insects both on grocery stores' shelves and on consumers' dining tables.

3. *Familiarizing youngsters with entomophagy*

Holding discussions and insect farming activities at school aiming to generate changes in collective behavior could prove particularly promising in training future entomophagists. Between February 2018 and January 2020, 662 fourth-grade students (15-16 years old) of a high-school situated in the Montreal suburbs took part in a project where they had the chance to learn more about edible insects as a sustainable foodstuff, while getting familiarized in class with insect farming methods. Surveys distributed at the beginning and following of these three-month projects allowed the assessment of students' acceptance towards edible insects. Three different student cohorts took part in this project: the first and second had the opportunity to raise crickets while the last were raising mealworms. It thus allowed me to perform both time-based and type-based analyses. Results showed that the project greatly enhanced the acceptance of participating youngsters towards entomophagy and also revealed that edible insect consumption had become increasingly normalized over the course of this short period. It suggests that the speed and impact of peer influence, particularly amongst youngsters, should be leveraged in promotional efforts to accelerate the adoption of edible insects.

4. Building sustainable and competitive insect farms

In order to pursue research in action in the field of insect farming and commercialization, I have teamed with other graduate students interested in complementary research aspects (environmental engineering and animal nutrition) as we co-founded an urban mealworm farm. This academic spin-off enterprise was launched as part of an urban agriculture solidarity cooperative, which allowed to reduce the infrastructural costs needed to start our farm and to achieve energy- and cost-effective innovative industrial ecology symbiosis, such as organic waste upcycling as well as the production and on-site use of organic fertilizer. This chapter discusses how our company has attempted to replicate circular processes occurring in nature as a proof of concept for the implementation of an urban insect farm that is both sustainable and lucrative, while exploring some of the challenges I was confronted with as an "entopreneur".

Research contributions

The COVID-19 crisis had shone a light on the weakness of globalized food supply chains. Inspired by naturally occurring processes, entomophagy and entotechnologies (i.e. insect farming processes) offer a holistic solution to reduce the ecological impacts linked to the production and consumption of conventional animal proteins, while fighting food waste and reducing the carbon footprint associated with the management of putrescible (i.e. rapidly decomposable organic) materials. Circular edible insect farming methods can reintroduce food wastes into the food chain while sustainably farming animal proteins within cities, therefore improving food security at the local scale. However, important barriers are hampering entomophagy adoption in Western cultures. My doctoral thesis aims to identify efficient strategies and tactics to successfully introduce edible insect farming and consumption at the city scale. It delves into cultural and economic issues at the consumer level and upstream in order to gain both public and private interest. It provides crucial insights to support the normalization and popularization of this sustainable practice. This great challenge represents an opportunity to prepare the food industry for the upcoming decades, which are more than likely to see many changes in both food supply practices and consumer demand.

Hence, its contributions are as follows: (1) a critical analysis of sustainability and security issues amongst food production systems; (2) the identification of marketing strategies promoting the adoption of innovative foodstuffs; (3) the assessment of Quebecker's food attitudes & preferences for novel protein alternatives; (4) the evaluation of farm to school programs' ability to alter youngsters' food norms; and (5) the identification of avenues to further integrate industrial ecology practices in urban farming, namely by supporting the development of synergies amongst various actors of the food scene.

Foreword to Chapter 2

I started writing the following chapter as part of a directed study tutorial that I undertook with my supervisor in marketing, during the second year of my doctoral path. As I was new to the sphere of marketing, this directed study gave me the opportunity to pursue focused work in the world of consumer behavior. Professor Lebel had first provided me with an elaborate reference list allowing me to get familiarized with key marketing concepts. As I began my readings, we would occasionally meet to discuss these topics. His guidance helped me get a grasp of the main consumer groups and understand the diverse elements involved in their decision-making processes.

As I was progressing in my understanding of Western barriers towards entomophagy – namely by leading consumer surveys which I will present in the following chapter – I gradually added new ideas to the initial paper that was written as part of my directed study. I ended up restructuring it completely in order to better address the different elements affecting the adoption of edible insects as an innovative food product. Once I was confident enough about the quality and originality of my paper – with the precious feedback of Professor Lebel and the input of my supervisor in biology (at the time when I was tapping into biology as a minor field of study for my interdisciplinary research) – I submitted it in October 2018 to the peer-reviewed *Journal of Insects as Food and Feed,* which has quickly gained audience and credibility in the sector.

The reviewing process took longer than expected. The journal's editors mentioned having difficulties finding appropriate reviewers, which wasn't surprising as edible insect marketing was a rather unconventional and understudied topic. Reviewers' comments were finally received in July 2019. They were addressed mainly by Professor Lebel and we submitted a revised version of the article in March 2020, which was quickly accepted the following month by the editor-in-chief. The paper was finally published in August 2020 (Marquis et al., 2020).

As the published version of the article has been the subject of important structural changes made by Professor Lebel (for which I unfortunately cannot claim authorship), the following chapter is rather based on the initial version of the article that was originally submitted for publication, which I revised myself in order to adequately reflect my own original contribution – still talking into account each of the reviewers' comments, but answering them in my own way (i.e. without restructuring the paper, as reviewers' comments concerned for the most part the integration of newly published papers). Its key findings have been used to elaborate a marketing plan for the edible insect company I launched in early 2019 (see Appendix G).

Chapter 2: Edible insect marketing in Western countries: wisely weighing the foodstuff, the foodie, and the foodscape

Introduction

Adequately feeding an increasing world population with a limited number of resources has been widely recognized as a major issue in the past decades. It is now one of the most wicked problems humanity has ever faced. Global meat consumption is rapidly rising – its demand is expected to reach 338 million tons per year by 2050 (Alexandratos & Bruisma, 2012) – not without triggering critical questions regarding its means of production. At the beginning of the century, 70% of all agricultural land was already dedicated to livestock farming or feeding, while accounting for 18% of all greenhouse gas emissions and using 8% of all freshwater reserves (Steinfeld, 2006). Due to increasing resource scarcity, consumers can expect meat prices to escalate drastically in the upcoming decades.

In order to attain greater food security while preserving environmental health, the main agenda of contemporary nutritional guidelines should be focused on achieving a reduction in populations' livestock-derived protein intakes, an issue which is gaining increasing social significance. Indeed, few other individual decisions could help solve these problems as efficiently (Davis et al., 2016). The rationale behind this is that systemic change in industrial regulations takes time to occur, while we have already met numerous ecological thresholds – as observed by the increase in catastrophic events occurring all across the world. Through their purchasing power, consumers can induce sustained economic pressure to accelerate a sustainable transition in food production systems.

Many consumer behavior studies aiming to generate such systemic changes have been focusing solely on increasing plant-based sources of proteins (de Boer & Aiking, 2011; Elzerman et al., 2011; Lea et al., 2006). But according to prospect theory (Kahneman & Tversky, 1979), humans tend to feel losses more intensely than gains. In cultures in which meat is a central meal component, it would take no less than a tsunami-size societal transition in order to substitute animal proteins by their vegetal counterparts (Schösler et al., 2012). Changes in food consumption habits generally prove more fruitful when linked with the identification of a foodstuff that can substitute the original product by successfully taking over its functions (Montanari, 1994). Therefore, instead of promoting a switch towards a completely vegetarian lifestyle, substituting conventional meat with another type of animal protein that is more sustainable might constitute a more acceptable short-term transition.

Insects are quickly becoming widely recognized as such an alternative. As compared to conventionally farmed animals, they require less water, feed, and space (Smetana et al., 2016) while creating very low pollution and waste (Oonincx et al., 2010). Due to the westernization of diets in rapidly urbanizing cities of the developing world (especially through the proliferation of fast-food restaurants), a growing number of individuals tend to adopt eating habits based on meat and excessiveness – similar to those that are now well entrenched in industrialized countries (Goodman & Robinson, 2013). The Western (i.e. amongst European-derived populations) aversion towards entomophagy (i.e. insect consumption) could thus negatively affect its worldwide practice, leading for instance to the loss of traditional knowledge related to consumable species and insect-based recipes (Chakravorty et al., 2013; DeFoliart, 1989).

However, dietary preferences can change quickly, with only a thin line separating appetite from disgust (Loo & Sellbach, 2013). As edibility is an evolving concept that not only adapts to social contexts but can also alter them, food choices are seen as both dynamic and ever-evolving (Shine, 2021). Hence, in Western societies, instinctual realignments with food have successfully occurred in the past. Marine scavengers such as lobsters, crabs, and shrimps – which could be described as sea-living insects, if one was to cut short on biological explanations – were once loathed by fishermen for getting entangled in their fishing nets. Today, they are widely considered as delicacies and can figure amongst the most expensive options in high-end restaurants' menus. In fact, van Huis (2017a) argues that marketing insects in the Western world may not seem as impossible as it was once considered. However, current marketing strategies – mainly stressing health and environmental benefits – are insufficient to encourage widespread insect consumption (van Huis, 2017b).

Previous studies aiming to find ways to trigger consumers' interest for edible insect products have largely focused on increasing products' familiarity (Megido et al., 2016; Tan et al., 2016a) as well as their organoleptic features – such as appearance, texture, and taste (Tan et al., 2017a&b). However, there remains a gap in the scientific literature in terms of applied and relevant marketing-focused suggestions to promote the purchase, the adoption, and the repeated use of edible insects. As human food habits are complex, only a diverse set of strategies will likely lead to overrun mere trial. In the following, I will attempt to identify efficient marketing tactics to promote edible insect consumption, which I will divide into three components: the food's attributes that satisfy established and evolving consumer preferences (the *foodstuff*); the consumer's characteristics such as his/her degree of adventurousness and the relative importance he/she devotes to the various attributes and benefits of a particular food product (the *foodie*); and the characteristics of the food environment amongst a specific culture (the *foodscape*). Altogether, the assessment of these three factors allows for the better identification of promising strategies to reach a larger group of potential insect consumers. They can help pave the way for the normalization – and perhaps popularization – of entomophagy in Western countries.

The Foodstuff

Many elements can influence food choices. Coveney (2013) suggests that they can be driven by two distinct factors, namely biological signals and psychological factors. Whereas the first relate to innate processes that are regulated by chemical messengers and influenced by individual genetics, the second are more prone to change over time as they involve cognitive phenomena that are often shaped by cultural conditioning. In its simplest expressions, a foodstuff is a substance ingested to feed the body in order to support its vital functions. Although edible insects easily fit into this definition, many people's fear and disgust for bugs are preventing them from seeing insects as potential food (Lammers et al., 2019; Ruby & Rozin, 2019). Relying on efficient marketing strategies might perhaps help reverse these cognitive barriers. Psychological processes influencing food choices are driven by a complex set of elements, some more salient than others in different environments or situations. Traditional drivers of food choices – such as convenience, sensorial appeal, and other hedonic drivers – are in conflation with evolving ones relating to health, wellness, safety, and social responsibility (Nunes, 2015).

Traditional Drivers of Food Choices

Based on their traditional consumption in many parts of the world, western governments are increasingly recognizing insects as a legitimate foodstuff (Lähteenmäki-Uutela et al. 2018).

However, their legal recognition status is not an end in itself. A closer look at the preferences that have traditionally influenced consumers in their food selection might reveal insights to help better support the incorporation of insects in Western diets. Unless cognitive barriers preventing insect consumption are alleviated, rational arguments and promotional incentives are likely to prove inefficient (Lewin, 1943). Insects' visual characteristics are largely responsible for shaping consumers' revulsion towards entomophagy (Shepardson, 2002). One relatively simple solution to overcome this negative reaction is to modify edible insect products' physical and chemical properties (Deroy et al., 2015). Organoleptic features - including cues like shape, colour, texture, odor, and taste – can all be manipulated in order to increase a foodstuff's sensorial appeal (Ramos-Elduroy, 1997). This can be achieved by processing (e.g. by grinding food ingredients to make them invisible) and/or product combination (Tan et al., 2016a; 2017b).

Food processing can help familiarize Westerners with unpopular foods and can lead to their greater acceptability (Martins & Pliner, 2005). Processed meat can increase consumer acceptance by making its animal origin less noticeable (Grunert, 2006) and the same can be achieved with insects. Product combinations can also normalize the perception of an unfamiliar foodstuff through positive contamination. Merging insects with an appropriate carrier product could thus help heighten their sensorial appeal (Tan et al., 2016a). In Copenhagen, the *Nordic Food Lab* has devoted sustained efforts in characterizing the taste of various types of insects, allowing them to identify interesting culinary combinations and to come up with delicious insect-based recipes. Integrating insects with ingredients and recipes that are already accepted in local food cultures can also imply edibleness and normalize its consumption (Shelomi, 2015; Tan et al., 2015). By incorporating raw fish to already familiar ingredients such as rice and vegetables, sushi greatly facilitated the adoption of uncooked fish in North America (Looy et al., 2014). Likewise, familiar preparations – such as burgers, pasta, or muffins – can also improve consumers' willingness to try unknown foods, as they can trigger positive sensory expectations (Tuorila et al., 1998; Yeomans et al., 2008).

Promoting insect integration in ready-to-eat meals could also lead to enhanced acceptability, curbing the challenge of having to learn how to cook and prepare this novel foodstuff (New Nutrition Business, 2014). Carefully selecting an adequate product name for marketed insect products constitutes another important aspect. Cognitive psychology and sensory sciences have clearly demonstrated the strong influence product names can have on altering the liking of unappealing foodstuff (Johnson, 2010; Spence & Piqueras-Fiszman, 2014). But this is not an easy task for marketers: whereas familiar names can increase neophobic consumers' acceptance for insect-based products, exotic names can be more appealing for neophiliacs (Deroy et al., 2015). In order to emphasize the ethical and sustainability benefits as well as the safety of alternative animal protein products, the *Good Food Institute* supports the use of the term "clean meat" (Friedrich, 2016) – which might sound familiar but not very exotic.

Consumers also tend to attach great importance on convenience, which covers any aspect of food decision, purchase, preparation, consumption, and disposal that can have an impact on peoples' time and energy expenses (Darian & Cohen, 1995). Millennials – having grown up in a consumer environment that could quickly satisfy their cravings – tend to set extremely high expectations for a product's convenience (Mushkin et al., 2012). As edible insects can be hard to find in Western supermarkets, potential early adopters of entomophagy are forced into a form of passive rejection (Shelomi, 2015). Higher product availability and exposure have been proven to stimulate the willingness to try novel food items (Loewen & Pliner, 1999), as well as the likelihood of consuming them in the future (Tuorila et al., 1994). Generating greater trial opportunities would thus greatly help to get consumers accustomed to edible insects (Costa-Neto & Dunkel, 2016).

Price also indirectly affects convenience, as the money consumers decide to spend on a product has likely been gained at the expense of time and energy. Edible insect's excessive prices in Western countries thus also represent another important barrier preventing their popular adoption (Dussault, 2017). Few investments have been made thus far by major food corporations in order to develop mechanized manufacturing practices (Dobermann et al., 2017). Current insect farming practices are thus generally still highly labor-intensive, which translates into quite expensive marketed products. While interest from the food industry is likely to arise once consumer demand will increase, greater supply itself can also prove highly effective in generating consumer interest (Shelomi, 2015). However, price also constitutes an extrinsic cue on which consumers can rely on to generate inferences on a product's quality, especially when they can't be inferred through available sensory or cognitive information (Kardes et al., 2004; Richardson et al., 1994). As many food attributes are often unavailable for consumers at the time of purchase, they must make their own mind based on the information available at that specific moment (Dick et al., 1990).

Evolving Drivers of Food Choices

For innovative foods to become adopted, they must be congruent with consumers' evolving preferences (Ryan & Deci, 2000). In the search for a sustainable and healthy lifestyle, urban dwellers are increasingly seeking ways to reconnect with the food that fuels their body (Morgan, 2015). But with the rising social significance of dietary health and the growing public awareness on food issues comes a lot of confusion regarding food healthiness. Food marketers often take advantage of this muddle, mixing up nutritional characteristics with misleading health claims on the benefits of different products (Schultz, 2015).

Motivational arguments to support entomophagy can be divided into two categories, namely promotional and preventive ones (de Boer et al., 2007). Whereas the former can be used to emphasize a product's wide-ranging benefits, the latter aim to dissociate edible insect consumption from potential threats, such as disease transmission. Although important marketing efforts to realign consumers perceptions and beliefs towards edible insects are critical, they must be carefully selected and used strategically, as mixed slogans are most often inefficient (Fenko et al., 2015). Moreover, neophiliacs and neophobics (i.e. attracted by or resisting new products, see the following section) both respond differently to cognitive and affective messages (*ibid.*). Hence, in order to avoid flooding consumers with confusing claims, marketing various edible insect product lines using distinct marketing messages could help more efficiently reach different potential consumer segments, each of them showing singular priorities and values.

As compared to various conventional meat products, roasted crickets are a much more interesting source of essential amino and fatty acids, vitamins, minerals, and fibres (Kinyuru et al., 2015). However, average consumers rarely spend time analyzing nutrition facts tables, either by lack of time, of interest, or of knowledge required to critically assess such information. Furthermore, these tables are often outdated and in conflict with contemporary progresses in nutritional science (Tarasuk, 2016). Emphasizing the personal health benefits of entomophagy in a clear and concise way could prove highly effective, as healthiness plays a strong role in influencing consumers' food choices (Verbeke, 2015). As Westerners now seem to strongly prefer foods without additives or artificial ingredients (Siegrist, 2008), commercializing insect-based products containing a short list of ingredients, combined with supporting marketing messages (e.g. using words such as "natural" or "organic") could also increase consumer acceptance towards this innovative foodstuff.

Social responsibility preferences are also on the rise. Ecological, social, and animal welfare concerns are increasingly gaining consumers' attention (van Loo et al., 2014). Even food security issues are making their way into the public sphere, which includes preoccupations around notions of food affordability and accessibility (Martin et al., 2016). Insect farming holds the potential to increase local and even household self-sufficiency – it requires very little space, materials, resources, and knowledge. Hence, it could enhance food security at many different scales. Although the benefits on land, feed, water, and energy use of insect farming as compared to other farmed animals are widely acknowledged in the scientific literature (van Huis et al., 2013), they still need to reach consumers' minds. At the turn of the millennium, the proliferation of images and testimonies in social and mainstream media revealing how animals can be treated in large-scale farming facilities has widely contributed to the popularization of vegetarian and vegan movements. In order to reach out to these consumer groups, and to avoid associations between insect and poultry or livestock industries, these same media could serve as platforms to promote the wide-ranging benefits associated with entomophagy. Transparency regarding insect farming practices should also be supported in these messages, namely by stressing that insects are not equipped with an emotional brain, which controls the ability to feel pain and suffering (van Huis, 2019).

The Foodie

A foodie refers to someone with enduring involvement in various things food-related (Johnson & Baumann, 2010). There are many types of foodies, each connecting with food in their own specific way. Foodies vary in terms of their levels of involvement with food, as well as the different motivations that dictate their dietary choices. If distinctive marketing approaches are to be tailored to different potential edible insect consumer segments, differentiating their main characteristics should help maximizing the efficiency of the strategies put forward to stimulate their interest towards such products. Although consumers will hereby be divided into broad categories according to the main drivers being responsible for dictating their food selections, such generalizations are only intended for the sake of the present exercise. Consumers' food preoccupations actually tend to encompass a diverse set of these factors, which all play a varying importance in decision-making processes – depending on their singular values and preferences.

A key step when marketing a new product is to identify its potential lead user groups (i.e. those most likely to adopt it). Generalizing their specific characteristics and motivations can then facilitate the identification of strategies likely to trigger their interest towards a specific product (Herstatt & von Hippel, 1992). Regarding edible insects, Verbeke (2015) described their lead user group (in the Western world) as being young males, highly neophiliacs and environmentally conscious, which translates into a high degree of food awareness and a weak attachment to meat. Interestingly, this suggests that two important consumer categories are likely to develop a curiosity for entomophagy, namely taste-oriented and reflection-oriented consumers (de Boer et al., 2007). Whereas those in the former group are most often motivated by the cultivation of an adventurous taste, the latter tend to be reflective about the overall implications of their everyday food choices (*ibid.*). It may appear paradoxical to have these two "opposite" consumer groups as potential entomophagy adopters, but it is what makes edible insects such an interesting foodstuff: they healthy, sustainable, unfamiliar, and (arguably) palatable. This represents a strong relative advantage as compared to other alternative proteins, as they can reach out to a wider range of potential consumers.

Taste-Oriented Consumers

Taste-oriented consumers are often less involved with food, a characteristic that would dispose them to adopt a rather impulsive shopping behavior (Verbeke & Vackier, 2004). They are believed to be more prone to cue-based decision-making at the time of purchase, and thus more likely to be influenced by different marketing tactics aiming to draw their attention (Hamlin, 2010). Even though they aren't typically concerned about questions of food security or sustainability, they tend to be interested in conceptual novelty associated with the way certain products are produced or processed, such as free-range or organic (Grunert, 2006). Usually highly adventurous and focused on sensorial stimulation, they attach few importance to price and convenience, but rather have a strong interest for cooking and commensality (Latimer et al., 2015). Such personal involvement with insect preparation is believed to alleviate the degree of disgust that can be felt by many people (Loo & Sellbach, 2013). Beyond eye-catching packaging, exotic food products like insects should thus provide cooking tips in order to further encourage these types of adventurous behaviors (Latimer et al. (2015). As taste-oriented eaters also like to discover new flavors, they tend to adopt curious, and sometimes even risk-taking food habits. Emphasising insects' novelty (in Western markets) and distinctive palatability could thus prove successful in turning such consumers into early adopters.

However, the disgust associated with insects in the Western world is such that entomophagy adoption – even amongst the most adventurous eaters – is likely to be hindered by the experience of neophobia (i.e. a reluctance to eat unfamiliar foods). Our genes are believed to be responsible for about two thirds of the factors influencing neophobia (Knaapila et al., 2007). It represents an efficient defence mechanism against poisoning, as it inhibits the ingestion of potentially toxic ingredients (Martins & Pliner, 2006; Verbeke, 2015). But the many safeguards nowadays preventing such foods from entering western food markets might render this behavior rather outdated and inconvenient. Neophobia is considered the most important barrier to overcome before Westerners can even consider integrating insects in their diets (Verbeke, 2015).

Tightly linked to neophobia is the cognitive disgust often felt towards insects, which varies from one individual to another. It is based on perceptual attributes, which do not rely on the product's quality or taste itself but rather on irrational factors (Deroy et al. 2015; Grunert, 2006). Beliefs associated with the nature or origin of food – often the result of social constructs which are largely defined by the culture of belonging (Le Breton, 2006) – can build strong reluctance towards unfamiliar products (Haidt et al., 1994). As disgust can hinder consumers' ability to make rational decisions, an approach focused on bottom-up (i.e. hedonic or sensory-related) processes is likely to help better support the effectiveness of utilitarian claims related with insects by initially developing consumers' positive feelings for entomophagy (Berger et al. 2018; Shine, 2021),

Moreover, insects are often perceived as a source of contamination, having been traditionally associated with decaying food, household pests, and carriers of diseases (Looy et al., 2014). But as insects are biologically more disconnected from humans than vertebrate livestock, the risk that they might carry pathogens or parasites is extremely low as compared to conventional meat (van Huis et al., 2013). As the perceived risk Westerners associate with edible insects negatively influences their willingness to purchase such products (Siegrist, 2008), it is essential to deconstruct such false assumptions in order for edible insects to be considered a potential foodstuff. Increasing the presence of edible insect products on the market and multiplying trial opportunities can help overcome neophobia, making it easier for consumers to recognize their palatability and related benefits (Martins & Pliner, 2006). Early sensorial exposure and increasing nutritional messages tied to edible insects can also positively affect reluctant behaviors, and even lead to increased willingness to try such novel food products (Reverdy et al., 2008).

Reflection-Oriented Consumers

Consumers who tend to be rather reflective in their food choices are most often characterized as well-educated individuals with a great sense of food awareness – concerned by factors such as naturalness, health benefits, and ethics (de Boer et al., 2007). According to the *Theory of Planned Behavior* (Ajzen, 1985), reflection-oriented consumers are involved in active and complex decision-making processes, mostly driven by their attitudes and values (Hamlin, 2010). These consumers tend to better understand the personal, social, and environmental consequences of their food choices, which ubiquitously reflects in their purchase decisions (Janhonen & Palojoki, 2015). Therefore, they are expected to respond better to marketing strategies that straighten the association between insect eating and its various related benefits.

According to Forestell et al. (2012), vegetarians and pesco-vegetarians (i.e. whose meat intakes rely solely on seafood) tend to be more preoccupied by ethical concerns when it comes to food choices. A study conducted by Verbeke (2015) revealed that about half of Western consumers were aware that high levels of meat intake were associated with increasing environmental pressure. It also estimated that consumers willing to reduce their fresh meat intake were 4.5 times more likely to be ready to adopt insects as a substitute. As they are restricted in their food options, vegetarians are less prone to food neophobia and more open to new culinary experiences. Positioning insects as a sustainable and healthy meat substitute could draw the attention of consumers who are trying to reduce the overall impact of their meat consumption – often seeking for alternative sources of protein and micronutrients (Elorinne et al., 2019). A better understanding of edible insects' nutritional habits and life cycles, as well as entomophagy's potential contribution to enhance food security and environmental sustainability, could help reach (pesco-)vegetarian consumers (see the following chapter for further discussions on this topic). Insects are currently the only source of animal protein that could quite easily be mass-produced within cities (namely by relying on vertical farming), thus diversifying the urban agriculture movement (Cabrera et al. 2015). Moreover, as edible insects can easily be farmed at the domestic scale, they can help facilitate low-income households' accessibility to highly nutritious foods (Müller et al., 2016).

Health represents another important factor that can influence reflection-oriented consumers' food choices. Hence, "selfish" arguments could be used to pull sceptical individuals – or those simply unpreoccupied by environmental and ethical issues – towards a different reflective path. Red and processed meat consumption has been found to enhance consumers' chances to suffer from cardiovascular diseases, type 2 diabetes, Alzheimer's disease, and various forms of cancer (Tappel, 2007). Vegetal proteins are a good alternative option but – as they lack one or a few of the nine essential amino acids required for the human body to thrive (St Jeor et al., 2001) – they must be carefully combined in order to ensure the good functioning of the body. This task can be more complicated for people who are allergic or intolerant to certain foodstuffs. For instance, one percent of the world population suffer from celiac disease, and up to 6% are thought to be gluten-sensitive (Mocan & Dumitrascu, 2016). Gluten represents an important protein group, containing elements that can be hard to find elsewhere, such as methionine, vitamin B, and iron (*ibid.*) – all of which are present in most edible insect species.

Finally, consumers vary in terms of the degree to which their food choices tend to be influenced by others (friends, families, cooking shows, advertisements, or celebrities) (Grunert 2006; Shelomi, 2015). At the very end of this spectrum are laggards, who are generally less educated consumers with both low degrees of adventurousness and food awareness (Latimer et al., 2015; Rogers, 2003). Tailored marketing tactics can be used to reach out to such consumers (neither taste-oriented nor reflection-oriented). Endorsement of a product by a trusted person is believed to help grasp consumers' attention, while facilitating the processing of the information conveyed and increasing its memorization (Keel & Nataraajan, 2012). Celebrity endorsement, for instance, can support the effectiveness of advertised messages and even increase consumers' preference for the endorsed brand (Ambroise et al., 2014). However, it is important to carefully select a credible endorser, who must be perceived to be in congruence with the advertised product (Fleck et al., 2012). The attributes of the endorser are thus fundamental (Amos et al., 2018). Selecting a legitimate expert in his field could increase consumers' trust regarding the associated benefits that are put forward, while allowing to decrease the perceived risk associated with the purchasing of a novel product (Biwas et al., 2006).

The Foodscape

If the landscape refers to a portion of land that can be grasped in a single view, the foodscape can be seen as a foodstuff's surrounding environment – whether at the micro scale (i.e. its packaging and positioning within a store) or at the macro scale (i.e. its cultural setting). Efficient product marketing strategies should take advantage of its foodscape, as it is more than likely to have an influence on consumers' purchase decisions and likeliness to adopt certain products.

The micro foodscape

Consumers take many purchasing decisions in stores (Nichols, 2012), most often dictated by emotional or visceral factors (i.e. "bottom-up") rather than rational or cognitive factors (i.e. "top-down"). Merchandising tactics and point-of-selection initiatives (e.g. location of a product within a store) can thus be used to nudge consumers in their purchase decision process. As people spend on average less than 12 seconds in a category display (Dickson & Sawyer, 1990), industry research suggests that product packaging has less than two seconds to capture shoppers' attention (Stephenson, 2016). Therefore, identifying an appropriate eye-catching packaging appears as important as to make sure the product is displayed in the right retail department. The right combination of different packaging attributes has the power to improve consumers' experience. It can prove significant in determining whether a product will be chosen or rejected (Piqueras-Fiszman & Spence, 2012). The appearance of a product's packaging will have an impact on its visual appeal for consumers. It might bring them to touch or grab the product. At that time, the packaging's material and its texture will influence its haptic feeling and sound, which will influence consumer's first impression of the product.

Visual similarity of unknown products with their familiar counterparts can improve consumers' willingness to buy them (Fenko et al., 2015). If insects are to be sold as a meat alternative, which type of packaging should they use? In order to prevent contamination, raw meat products are generally wrapped in plastic. But if consumers switch from conventional meat to insect-based proteins for environmental concerns, perhaps a careful selection of environmentally friendly packaging could render the product more cohesive to consumers' values. This should definitely involve steering clear from overpackaging or unrecyclable materials (e.g. expanded polystyrene, multilayered plastics, or mixed materials). On the other hand, if processed insect-based products are to be sold frozen (e.g. meatballs or sausages), perhaps a better look at the packaging used in the frozen meat section might better strengthen their sensorial appeal (Hoek et al., 2011).

However, are consumers really more likely to consider insects as a functional substitute for conventional meat, rather than simply an optional food? Identifying a product's function impedes on its compatibility and complexity – two important attributes dictating whether or not innovations will successfully diffuse in a society (Rogers, 2003). Consumers' perceived food category appropriateness regarding a specific foodstuff can impede their sensory experience at consumption and even significantly modulate its overall acceptability (Shine, 2021). Marketing edible insects as an alternative form of animal proteins creates high expectations regarding its similarity with such products (Tan et al., 2016b). Yet, meat is recognized as a sensitive domain in which consumers' likings and aversions tend to be deeply rooted as compared to other food categories (Tucker, 2014). Due to consumers' strong attachment to meat, such substitutes are expected to have highly similar characteristics (Elzerman, 2006). But it is hard for insect products to imitate meat's sensorial properties, most particularly its texture – as the vast majority of edible insect products on the market are sold completely dehydrated. Moreover, insects are currently unable to compete economically in this food category, which represents another strong barrier to their regular purchase.

Therefore, it might be more appropriate to classify edible insects with other optional foods, such as dietary supplements or snacks (DeFoliart, 1989). Shelomi (2015) suggests that insect food products share quite similar sensory attributes and functional characteristics with nuts – another quite versatile foodstuff associated with a plethora of food preparations (Shine, 2021). Moreover, promoting insect snacks' portability and convenience could prove particularly effective in societies where productivism is highly valued (Schösler et al., 2012). Indeed, about half of all adult food consuming occasions are now undertaken alone, leading to the growing popularity of snacking "on-the-go" (Hartman Group, 2012). People are also on the impression that smaller meals are healthier. The past years have seen the proliferation of many companies offering insect-based snacks (New Nutrition Business, 2014). A study conducted by Gmuer et al., (2016) reveals that marketing insects in such a way would constitute a promising avenue to increase consumers' acceptance.

However, Shine (2021) suggests that a one-category-fits-all approach regarding insect products might prove less effective than a more differentiated one, which could be better suited for such a versatile foodstuff that holds the potential of reaching a broad range of consumer segments. Nonetheless, further market research should be driven in order to better assess consumers' specific preferences for edible insect products. For example, they could aim to identify whether insects are more popular in sweet or in savoury preparations of all kind (this question is addressed in the following chapter). Tan et al. (2016a) have previously attempted to investigate this topic, but they were only able to assess it using a set of prepared foods images.

The macro foodscape

The sociocultural environment prevailing in a specific location plays a great role in shaping its gastronomic scene. Gastronomy in turn plays an important role in defining the degree of openness of a culture towards outside food influences (Meyer-Rochow, 2010). Cosmopolitan cities are characterized by the presence of a highly culturally diversified gastronomic scene, revealing a complex system of norms, rules, and representations. Gastronomy can help building bridges between different cultures that share the same territory. Hence, it can widen prevailing cultural norms, which are known to represent strong psychological factors influencing food preferences and choices (Mela, 1999). Indeed, consumers' critical food practices are often found to be the expression of their cultural identity (Morgan & Sonnino, 2010).

It has been demonstrated that Australian adolescents living in multicultural cities were more willing to consume unfamiliar food products than the ones living in rural areas (Flight et al., 2003). As a matter of fact, innovators (i.e. first adopters of new products) have been described as predominantly cosmopolite (Rogers, 2003). The cultural diversity of restaurants in cosmopolitan cities thus constitutes an interesting medium to alleviate local consumption barriers towards insect-based foods and to introduce Western populations to entomophagy – a traditional practice in many Asian, African, and South American cultures. Not only can gastronomy dictate edibleness, but it can also elevate insects to the gourmet food status, thus potentially stimulating consumer demand for such products (Johnson, 2010).

According to a study conducted by Verbeke (2015), one out of five Western consumers would claim to be ready to eat insects regularly. But is it appropriate to consider Western cultures as a whole, without considering their regional singularities? Tan et al. (2015) suggested that future research should give emphasis to sociocultural factors, as they play a great role in influencing insect consumption. Indeed, evaluating disparities relating to the acceptance of entomophagy amongst geographic, linguistic, and cultural populations is essential in the development of tailored marketing strategies.

Previous studies have shown that the production of raw and transformed insect food products are on the rise in Canada (Dussault, 2017), and that local policies may favourably affect insect marketing in the country as compared to other Western civilizations (Lähteenmäki-Uutela et al., 2018). However, despite consumer acceptance surveys conducted in various countries in the Western world (Megido et al. 2016; de Lanauze, 2015; Lacey, 2016; Lensvelt & Steenbekkers, 2014), there remained until recently a data gap in Canada. Recently, a survey reaching 750 respondents revealed important national dissimilarities between French Quebeckers, English North Americans, and French Europeans with regard to knowledge, behaviors, and motivations towards entomophagy (Hénault-Ethier et al., 2020). For instance, French Quebeckers were found to exhibit a heightened attention for environmental and health motivations. Such findings strengthen the importance of tailoring insect marketing strategies to regional foodscapes.

Conclusion

Edible insects can be seen as an opportunity to develop marketers' adaptability to evolving food preferences. It represents a great challenge, but it can provide crucial insights for the food industry – especially as increasing environmental constraints are likely to induce necessary changes in both food supply and demand in the upcoming decades. Succeeding to this challenge implies to find the appropriate set of strategies aiming to gradually turn reluctance for alternative and innovative forms of complete proteins, such as insects, into craving.

In order to do so, developing a proper understanding of what processes are involved in dictating consumer food choices is critical. For a successful transition from conventional meat consumption to sustainable alternatives to take place, we must increase consumers' acceptance for "future foods" – ones that enable mindful eating, in line with contemporary preoccupations for tastiness, healthiness, sustainability, and social solidarity. Altogether, assessing the foodstuff, the foodie, and the foodscape can provide key insights on efficient marketing strategies to be used to overcome perceptual barriers and to promote the adoption of edible insects in Western societies.

First, it appears essential to effectively assess and control an innovative foodstuff's characteristics in order to ensure its adequacy with consumers' traditional and evolving drivers of food choices. Then, taking a closer look at major consumer characteristics reveals crucial differences amongst the motivations and concerns that could potentially lead Westerners to develop an interest in entomophagy. For instance, as food eaters, we all express distinctive degrees of adventurousness and awareness towards the ingredients we ingest. Hence, our food choices can be influenced by a varying set of factors. Considering the food environment at its different scales can also yield useful insights to enhance commercialization and marketing efforts aiming to nudge consumers in their purchasing decisions. On this aspect, identifying a strategic product category where edible insects should be displayed remains a critical issue deserving further investigation.

Developing such proper marketing strategies to promote insect consumption requires a regionalized understanding of consumers' attitudes and perceptions, namely by considering the sociocultural distinctions prevailing amongst them. To this end, it is essential to assess local populations' specific food preferences and behaviors. Only such an exercise – integrating sociological and geographical considerations – can lead to the elaboration of efficient regional marketing efforts aiming to turn consumers' disgust towards entomophagy into curiosity, and eventually into a regular practice.

Foreword to Chapter 3

If you have read the concluding statement of the previous chapter, the following one needs no introduction. Marketing strategies that can help overcome consumers' reluctance towards entomophagy are numerous. Attempting to implement them all at once is not likely to prove very effective. Assessing behaviors and preferences of local populations can help better identify tailored marketing strategies to be used in specific sociocultural contexts.

Prior to the realization of my own pan-Canadian survey, I joined a research group that had already circulated a survey in 2016 (750 respondents) aiming to compare French Quebeckers' position towards entomophagy to that of French Europeans and English North Americans. I contributed to the results' interpretation and writing of a paper which was first submitted in October 2018 for publication in the *Journal of Insects as Food and Feed*. Reviewers' comments were received in July 2019 and we have sent a revised version of the paper in November. It was published online in February 2020 before being included in a full issue of the Journal (Hénault-Ethier et al., 2020).

The knowledge I gathered helped refine the methodology for my own Canada-wide survey, which was distributed online between December 2017 and December 2019. Many of the questions initially developed in the previous study with the help of survey professionals, entomophagy specialists, and entrepreneurs were retained in the second survey to allow longitudinal comparisons, although some novel data gaps were also addressed. Initial results of these surveys were presented as part of an international entomological congress (Marquis et al., 2018).

After obtaining ethical clearance (see certificate in Appendix H), tasting activities with edible insect products were also performed in order to provide complementary data, supporting the importance of sociological and geographical considerations when assessing consumers' barriers, motivations, and preferences towards entomophagy.

Altogether, these findings add to the increased scientific literature on notions of edibility that nourish the field of food geography research. The paper is intended for publication in the *Food Quality and Preference* scientific journal.

Chapter 3: An evolutionary and comparative analysis of Quebeckers' acceptance for edible insects combining survey results and product tastings

Introduction

The COVID-19 crisis has been found to lower consumers' demand for animal food products (Attwood & Hajat, 2020). As a result, alternative proteins are quickly gaining significant consumer interest. Amongst them are edible insect-based foods – having recently conquered increasing shelf space in Western food stores. Although many researchers have clearly demonstrated edible insects' growing popularity in many societies across the world (particularly since the mid 2010s), none have actually attempted to evaluate how this trend has evolved amongst any specific culture in the past few years. More importantly, very few research have attempted to validate and complement market research surveys by assessing consumers' specific preferences when given the opportunity to actually taste insect products. As a result, companies marketing such products might be misled in their efforts to overcome consumers' barriers to purchase – either by commercializing the wrong products or by emphasizing inefficient or insufficient promotional arguments.

The edible insect industry is in rapid evolution – with a variety of new products regularly making their way into the market (Shockley et al, 2018), as well as sustained media coverage (Payne et al., 2019). Recently published results of a 2016 survey comparing French Quebeckers' knowledge, behaviors, and motivations towards entomophagy (i.e. insect consumption) with that of other North American and European consumer groups demonstrated a rather generalized willingness amongst this specific socio-demographic group (Hénault-Ethier et al., 2020). As pinpointed by its authors, Quebec represents a culturally distinct society in which roughly 95% of the population speaks French and where economic, political, and cultural (including culinary) views and practices differ significantly with those of its English North American counterpart neighbors. Its prevailing food culture is somewhere at the convergence of that of its American neighbours and that of its French ancestors. As entomophagy's popularization requires sustained geo-specific and geo-targeted efforts (Labrecque et al., 2006; Piha et al., 2018), the present research aims to assess the very recent evolution of entomophagy acceptance and of its practice amongst French Quebeckers, as well as their preferences for edible insect products. Additionally, it aims to evaluate how they compare to other Canadians in terms of their future intentions, motivations and concerns when it comes to entomophagy.

As part of the present study, we will also compare the degree of openness to entomophagy of carnivorous Canadians with that of those who are either non-meat eaters or are attempting to achieve a reduction in their conventional meat intakes – as these consumer segments could prove particularly interested towards edible insect products. With the emerging cultivation of an environmental consciousness, people are increasingly recognizing the environmental impacts of their meat consumption (Sanchez-Sabate & Sabaté, 2019). As a result, more Canadians than ever before are now adopting a vegetarian lifestyle (Vergeer et al., 2020). But as meat represents a very sensitive food domain, understanding the ecological impacts of a carnivorous diet is often insufficient to lead to critical changes in consumers' food habits (Dagevos & Voordouw, 2013). Rather than switching to a strictly vegetarian diet, consumers might thus be more willing to substitute conventional meat in their diet by a product that could successfully take over its functions (Montanari, 1994). Entomophagy was indeed found to be a largely accepted practice amongst Dutch vegetarians, whether it be due to the limited ecological impacts of insect production, to the fact that many people still don't consider them as animals, or because of their (alleged) incapacity to feel pain (House, 2019).

Vegans, however, tend to follow stricter principles in their food choices. Although some might refer to themselves as ''*veganish*'' – willing to supplement their plant-based diet with insects (Fischer, 2016) – most vegans refuse to consume foods of insect origin (Pantuso, 2019). Indeed, if strict vegans do not eat honey, chances are most of them wouldn't either feed on insects. Nonetheless, urban beekeeping initiatives have significantly gained in popularity in the past decade or so – an ecological citizenship manifestation demonstrating a strong desire for city residents to reconnect with nature (Sponsler & Bratman, 2020). After domesticating bees for honey production, would people be ready to consider rearing edible insects at home in order to fulfill their dietary needs? It is a question worth asking our surveyed participants. Although such an idea might seem to be coming from a science-fiction movie scenario, micro-livestock are actually being investigated as a self-sufficient source of protein for astronauts (Katayama et al., 2008; Tong et al., 2011). Indeed, insects are expected to be central in building bioregenerative life support systems in space.

In a *conjoint analysis* perspective (Green et al., 2001), the present research is complemented with product tastings in order to help better assess French Quebeckers' preferences for edible insect foods. These tastings provide interesting complementary information to survey results, which potential in providing reliable insights for the industry is rather limited – namely because surveys cannot adequately take into consideration food products' sensory attributes (Bellaco & Gracia, 2020). Comparably to consumers seeing a new foodstuff appearing on their favourite grocery store's display, surveyed respondents are asked to mark their preferences based on the sensory expectations they can infer using a restricted set of product attributes. They have to rely on the information they can gather (i.e. search and credence attributes) rather than on their actual sensorial experience with a specific product.

While some food product characteristics can more easily be evaluated by consumers before purchase (i.e. extrinsic cues), others can only be evaluated by relying on haptic feeling and consumption (i.e. organoleptic features). After deciding whether or not the sensory expectations they had initially inferred were valid, consumers can finally determine their degree of satisfaction towards the product, which in turn dictates if initial (or repeated) purchase is likely to occur. Hence, it is common for marketers to rely on tasting activities (more often in points of sale, so that consumers can immediately purchase the product before it spurts from their memory) as a way to get consumers familiarized with a novel food product – especially when they are confident enough that its smell, its taste, and its mouthfeel altogether form a successful combination.

Integrated with efficient product marketing, appealing sensorial characteristics can help developing consumers' acceptance for novel food products (Simeone & Marotta, 2010). Jointly assessing the relative importance consumers grant to various informational and extrinsic cues (e.g. through surveys) with that of sensorial or intrinsic product attributes (e.g. through tastings) is thus likely to provide more precise and reliable information on which food marketers can rely on before committing to launching a new product on the market (De-Pelsmaeker et al. 2013; Grunert, 2015). A multidisciplinary approach involving the sociocultural assessment of consumers' attitudes and intentions, combined with that of their hedonic appreciation for specific food products, can be expected to help determine food choices with a greater sense of reliability (Köster, 2009).

Methodology

Between December 2017 and December 2019, surveys were distributed online (*Google Forms*), in both English and French versions. Relying on the snowball effect, they were circulated through various academic and non-academic networks. A 30-second promotional video was created and shared on the *David Suzuki Foundation*'s *Facebook* page[7] as well as in an issue of their weekly column dedicated to issues relating to science and the environment (*Science Matters*)[8] – which was also shared in a dozen major web media outlets – with a global estimated reach of four million people.

Figure 1. Survey promotional video Facebook post from the David Suzuki Foundation

According to respondents' past experience and future intentions relating to insect consumption, the number of questions they were asked varied from 32 (for those having never eaten insects before and not intending to do so in the future), to 40 (for those having never eaten insects but mentioning being willing to try them), and 41 (for those having already tried eating insects) (see questions in Appendix I). Some of the questions initially developed by Hénault-Ethier et al. (2020) with the help of survey professionals, entomophagy specialists, and entrepreneurs were retained in this second survey to perform longitudinal comparisons. These questions mainly related to respondents' past experience and future intentions regarding entomophagy. Some novel data gaps were also addressed, aiming to reveal insights on consumers' preferences for insect foods as well as on their main motivations and concerns for such products – thus helping better assess the potential efficiency of diverse edible insect marketing messages. Closed questions (yes or no),

[7] www.facebook.com/watch/?v=10156274299763874

[8] www.davidsuzuki.org/story/save-planet-eat-insect/

those relying on multiple choices, and those using a Likert scale (from 1 to 5: totally disagree; quite disagree; neutral; quite agree; totally agree) were preferred in order to facilitate statistical analyses.

First, respondents were asked five questions aiming to assess their knowledge towards entomophagy. Then, they were asked two questions about their past experience and future intentions with entomophagy, followed by two questions aiming to assess the frequency of this consumption and the motivations why they have engaged or would be willing to engage with insect consumption. Respondents mentioning being completely closed to the idea of eating insects were simply asked about the main barriers driving their reluctance, whereas the others were asked eight questions aiming to assess their preferences and concerns for such products. Next, all respondents were asked five questions about their general food habits, followed by ten questions relating to their beliefs regarding the present industry and their predictions as for the future evolution of edible insect farming and consumption. Afterwards, seven questions were asked in order to assess their socio-demographic situation (gender, age, occupation, education, country of origin, province currently lived, and income).

Finally, respondents were asked about where they had heard about the survey and were given the opportunity to provide additional comments as well as their personal email address if they wished to be sent a link to consult the study once it was published. All the answers were compiled in a database (*Excel* software) and analyzed (*SPSS* software) using correlations and chi-squared tests. Only responses from respondents living in Canada at the time of completing the survey were analyzed (n=727), which resulted in the removal of 62 forms (26 from the U.S., 20 from Europe, six from undisclosed locations, three from Latin America, three from Asia, three from Oceania, and one from Africa). Data regarding age, education, and income were grouped into broader categories, which were similar to those used in the 2016 survey in order to perform statistical comparisons.

In order to draw complementary conclusions regarding consumers' preferences for edible insect products, tastings have also been carried out using four ready-to-eat cricket and mealworm products (both whole and processed). Quebecker respondents having: (1) completed the survey in French; (2) mentioned a willingness to consume edible insects in the future (whether for the first time or not); (3) indicated living in the Montreal metropolitan area (for the sake of simplifying logistics, filtered based on the postal code they had provided); and (4) provided their personal email address in the survey, were all contacted and asked if they would be willing to participate in an insect product acceptability test.

A dozen participants fitting these criteria accepted to take part in the tastings. Due to the sanitary restrictions in line with the COVID-19 pandemic, tastings were performed through a series of individual video conference meetings with the interviewer. According to the availability they had provided, tasters were each assigned a specific schedule. They were delivered a bag containing the four products to be tested and were instructed not to open it until the scheduled tasting: (1) whole unflavored dried mealworms; (2) whole seasoned dried crickets; (3) homemade whole-grain savoury crackers (containing 20% powdered mealworms); and (4) processed sweet-flavored energy bars (containing 10% powdered crickets). Each of these products were farmed and processed locally. Due to the absence of savoury processed insect products on the local market at the time of performing tastings[9], crackers were home baked[10] specifically for this activity. Such a variety of insect products make it possible to assess consumers' preferences in terms of appearance, smell, texture, and taste (i.e. crickets versus mealworms, visible vs processed, homemade vs industrial, 10% vs 20% and 100% insect content, crispy vs soft, unseasoned vs seasoned, and sweet vs savoury). Energy bars and crackers have been identified as the two edible insects products for which American consumers show the highest willingness to eat, scoring higher than 28 other products including protein shakes, cookies, candies, pasta and alternative meats (Ardoin & Prinyawiwatkul, 2020).

The group of tasters selected was composed of six women and six men, averaging 37 years old (standard deviation or s.d. 7.6). Ten of them had already experienced eating insects before (mainly mealworms and crickets, either whole or processed) but none of them were considered regular insect consumers (i.e. eating insect products at least once a week). When tastings were performed, participants were asked a series of questions aiming to assess each products' appearance, their palatability and taste, as well as tasters' potential interest in purchasing such products (see Appendix J for questions).

<u>Survey results</u>

Respondents

Of the respondents completing the survey, 60% (n=438) used the English questionnaire – 83% of which indicated living in provinces outside of Quebec (Table 1). Of the respondents choosing to use the French questionnaire, 95% indicated living in the province of Quebec at the time of completing the survey. These respondents – both living in Quebec and choosing to use the French questionnaire – (n=271) will be referred to as QcFr (thus allowing to achieve time-based analyses with Quebeckers from the 2016 survey by Hénault-Ethier et al., who will be referred to as QcFr16). Respondents having either completed the survey in English or having mentioned living in provinces other than Quebec will be referred to as Can (n=446). Ten respondents chose not to disclose the province in which they lived. They will be excluded of these two groups (QcFr and Can) but will be included in global analyses (in the "all" category, when comparisons will be made between QcFr and Can).

Table 1. Provinces where French and English respondents disclosed currently living

		Quebec	Ontario	Maritimes*	British Columbia	Prairies**
French	n	271	4	6	2	1
	%	95.4%	1.4%	2.1%	0.7%	0.4%
English	n	74	188	26	92	53
	%	17.1%	43.4%	6.0%	21.2%	12.2%

*New Brunswick, Nova Scotia, and Prince Edward Island
**Alberta, Saskatchewan, and Manitoba

[9] Insect-based chips were expected to launch in December 2020, but the manufacturer encountered production delays.

[10] Ingredients (20% sunflower seeds, 20% pumpkin seeds, 20% powdered mealworms, 13% sesame seeds, 13% chia seeds, 13% flaxseed, salt, and water) were mixed, spread evenly on parchment paper, and baked for 40 minutes at 150°C.

Participants having disclosed their country of origin were first manually grouped into seven categories (Table 2), namely Canada (78%), USA (6%), Europe (8%), Latin America (1.5%), Asia (1.5%), Africa (0.5%), and Oceania (0.5%). Others (4%) chose not to answer this question. The vast majority of respondents mentioned having been aware of this survey through educational networks (28%) or through environmental organizations (about 56% via the David Suzuki Foundation). Therefore, the socio-demographic profile of our respondents cannot be considered representative of the Canadian nation as a whole.

Table 2. Respondents' country of origin

	N/A	Canada	USA	Europe	Lat. Am.	Asia	Africa	Oceania
n	29	564	44	59	11	11	5	4
%	4%	78%	6%	8%	1.5%	1.5%	0.5%	0.5%

When asked to specify their gender, 68% selected “female”, 30% selected “male”, and the others (n=15) either chose not to answer this question or didn’t relate to any gender (Table 3). Gender distribution was similar amongst QcFr and Can populations (P = 0.275). Differences between male and female respondents for QcFr have been intensified from 26% in 2016 to 34% in the present survey (predominantly females). Age populations were found to differ significantly (P>0.001) between QcFr and Can, with 58% of QcFr aged between 25-44 and 56% of Can aged over 44. Compared to the 2016 survey, the percentage of QcFr participants found in the 25-44 and 45-64 age groups are quite similar. However, the present survey is characterized by significantly fewer QcFr respondents below the age of 25, being largely replaced by respondents over the age of 64.

Table 3. Gender and age of respondents

		Gender			Age				
		N/A	M	F	NA	<25	25-44	45-64	>64
QcFr16	n	*10*	*169*	*291*	-	*82*	*273*	*106*	*10*
	%	*2%*	*36%*	*62%*	-	*17%*	*58%*	*23%*	*2%*
QcFr	n	5	86	180	0	27	156	65	23
	%	2%	32%	66%	0%	10%	58%	24%	8%
Can	n	10	129	307	9	50	139	173	75
	%	2%	29%	69%	2%	11%	31%	39%	17%
All	n	17	218	492	11	77	298	239	102
	%	2%	30%	68%	1%	11%	41%	33%	14%

Respondents were for the vast majority (69%) university graduates (no significant difference observed between QcFr and Can: P=0.216) and 19% of them were current students (still quite similar, with P=0.789). Regarding their personal annual income, respondents were grouped into three categories (Table 4): below 30k \$ (27%), between 30k \$ and 70k \$ (35%), and over 70k \$ (22%). This time, significant differences were observed amongst populations (P=0.001), although it could be explained by the fact that twice as many Can respondents (as compared to QcFr) chose not to disclose their income. As compared to QcFr16, our survey shows a lower proportion of QcFr university graduates and a higher proportion of respondents earning at least 30k \$ yearly (which could be explained by the higher prevalence of respondents over the age of 64).

Table 4. Highest academic degree obtained by respondents

	Education				Income ($/year)			
	N/A	Elementary or high school	College	University	N/A	<30k	30-70k	>70k
QcFr16	1%	5%	19%	75%	*11%*	*44%*	*31%*	*14%*
QcFr	1%	9%	23%	67%	10%	26%	43%	21%
Can	1%	11%	18%	70%	19%	28%	31%	22%
All	1%	10%	19%	69%	16%	27%	35%	22%

Knowledge, past experience, and future intentions towards entomophagy

When asked if they had already heard of the practice of insect eating, 90% of Can and 97% of QcFr answered yes (93% average; P<0.001). In the previous survey, 97% of QcFr16 had also answered positively to the same question. Regarding whether or not they were aware that this was a common practice for about a quarter of the world's population, 50% of Can and 71% of QcFr answered yes (P<0.001). Questioned regarding their awareness about the fact that edible insects could represent a sustainable alternative to conventional meat, 80% of Can and 93% of QcFr answered in the affirmative (P<0.001).

Respondents were then asked if they had ever willingly consumed insects. No significant differences in answers were observed when comparing their gender, age groups, education, and personal income. About half of the respondents (49%) answered positively, with a greater proportion of QcFr (54%) as compared to Can (45%) (P=0.033). QcFr16 had shown a positive response rate of 50% to the same question. Respondents' province of residence was found to have a significant impact (P=0.004) on their prior experience with insect consumption (Table 5). Those from coastal provinces (British Columbia and the Maritimes) showed a higher positive response rate (respectively 64% and 53%), followed by Quebeckers (49%), and other provinces (41% for both Ontario and Prairies residents).

Table 5. Respondents' past experience with insect consumption according to their province of residence

		Quebec	Ontario	Maritimes	British Columbia	Prairies
No	n	175	114	15	34	32
	%	51%	59%	47%	36%	59%
Yes	n	170	78	17	60	22
	%	49%	41%	53%	64%	41%

Questioned about their willingness to try eating edible insects in the future, 66% of the respondents who had no prior experience with entomophagy (n=374) answered positively, with Can (73%) showing greater motivation as compared to QcFr (52%) – and so did QcFr16 (62%). Respondents who had already willingly consumed insects (n=353) were then questioned about their willingness to repeat the experience. Responses were largely positive (Table 6), 92% of respondents answering yes and 46% of them mentioning having already done it. QcFr and Can were once again characterized by a significant difference in their responses (P=0.003): 7% more QcFr were willing to eat insects again and 17% more had already done it. To the same questions, QcFr16 had only been offered the possibility to answer yes or no, 94% of them answering positively (which is 2% lower than QcFr in the present survey).

Table 6. Willingness to repeat edible insect consumption

	No, never	No, I don't think so	Yes, probably	Yes, I already did
QcFr	1%	3%	44%	52%
Can	1%	10%	54%	35%
All	1%	7%	50%	42%

As for the occurrence of this practice, the majority of respondents (55%) mentioned having only eaten insects once. Responses from QcFr and Can revealed dissimilarities in their answers ($P<0.001$), QcFr being more likely to have adopted a regular insect consumption (either yearly, monthly, or weekly) (Table 7). When comparing QcFr to QcFr16, se can see that weekly consumption amongst respondents jumped from 0% to 8%, while monthly consumption increased from 6% to 9%.

Table 7. Occurrence of insect consumption amongst respondents having already willingly eaten insects

	Once	< Yearly	Yearly	Monthly	Weekly
QcFr2016	*59%*	*n/a**	*35%*	*6%*	*0%*
QcFr	46%	19%	18%	9%	8%
Can	61%	27%	6%	3%	3%
All	55%	23%	11%	6%	5%

*Non-existent category in the survey by H-É et al. in 2016

Motivations, preferences, and concerns towards edible insect products

In order to assess respondents' main motivations for either having consumed or being willing to try eating edible insects, a list containing specific factors was provided. They were asked to attribute a rating ranging between one and five (from totally disagree to totally agree) for each of these factors (Table 8). Respondents having already consumed edible insects ("experienced", n=347) marked their main motivational driver as being curiosity (4.52), followed respectively by personal challenge (3.36) and ecology (3.33). As for respondents who had never previously eaten insects but mentioned being willing to do so ("open to experience", n=247), they were motivated by broader ranging factors: ecology (4.29) coming first, followed by curiosity (4.05), animal welfare (3.75), and health (3.51).

Table 8. Degree of importance (1 to 5) given to six motivational factors for eating edible insects

	Curiosity	Health	Ecology	Animal welfare	Personal challenge	To be noticed
Experienced	4.52	2.90	3.33	2.85	3.36	1.84
Open to experience	4.05	3.51	4.29	3.75	3.28	1.55

Respondents who had never tried eating edible insects and mentioned not being willing to do so in the future (n=127) were provided with a list of eight factors. They were asked to select each of those that motivated their reluctance (disincentives). They also had the opportunity to provide any additional factors. Appearance and texture were by far the most often selected factors in the list, chosen respectively by 87% and 73% of respondents. Other factors were, in order of importance, the fear of getting sick (39%), mistrust regarding the origin of products (34%), taste (32%), the lack of farming and processing standards (24%), availability (13%), and price (5%). Although vegetarianism or veganism didn't appear on the provided list, 22% listed it as an additional factor.

Respondents who mentioned being open to consuming edible insects in the future (n = 572) – whether it be for the first time or not – were asked a series of questions regarding their preferences and concerns towards edible insect products. Questioned as if they would prefer eating insects incorporated into sweet rather than savoury recipes (on a scale of 1 to 5), respondents were quite divided, although their average score of 2.58 (halfway between quite disagree and neutral) pointed towards a slight preference for savoury recipes (QcFr and Can showed similar responses, with P=0.782). Respondents were much less ambivalent when asked whether or not they considered that edible insects could potentially replace their meat consumption: 84% answered negatively, 10% positively, and 6% didn't eat meat (Table 9). A higher proportion of Can (43%) as compared to QcFr (29%) answered "not at all" (P=0.004).

Table 9. Willingness to consider edible insects as a meat alternative

	Not at all	Probably not	Probably	Absolutely	I don't eat meat
QcFr	29%	57%	8%	1%	5%
Can	43%	40%	9%	1%	7%
All	38%	46%	9%	1%	6%

As for the form(s) in which they would most willingly consume edible insects (they could select as many answers as they wanted), 88% of all respondents selected "in powder or flour", 57% "crushed into pieces", and 26% "whole" (Table 10). Each of those three forms were selected in a larger proportion by QcFr as compared to Can (powdered: P=0.007; crushed: P=0.247), and for whole insects the difference was significant (P<0.001, with 39% for QcFr versus 19% for Can). When questioned as if they would rather eat crickets than mealworms (the two most common types of insects marketed for human consumption in Western countries), both sociodemographic groups selected similar responses on a Likert scale of 1 to 5, indicating a slight preference for whole crickets (with an average response of 3.35, so somewhere between neutral and slightly agree) and a rather neutral position for insects in the powdered form (3.08).

Table 10. Preferred forms for consuming edible insect products

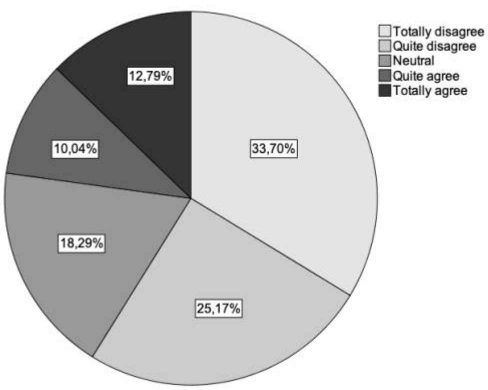
	Whole	Crushed	Powdered
QcFr	39%	60%	93%
Can	19%	55%	85%
All	26%	57%	88%

Still on a scale of 1 to 5, respondents agreed slightly (3.49) to the statement "I would prefer eating insect-based processed foods rather than cooking them myself", they agreed more strongly (4.25) to "I would give great importance to the origin and farming conditions (traceability) of insects before consuming them", and they agreed even stronger (4.51) to "I would accept to eat insects fed on clean organic waste originating from controlled food transformation processes". No significant difference to none of these questions was observed between Can and QcFr.

Beliefs and predictions

Respondents were questioned about their beliefs and predictions regarding the future of edible insect farming and consumption (once again using a scale of 1 to 5). Two thirds (66%) agreed (either totally or moderately) and 10% disagreed (also totally or moderately) that humans should eat more insects, 74% agreed and 8% disagreed that the practice of entomophagy could grow in North America, while 75% agreed and 7% disagreed that insects should be available on grocery stores' shelves. When asked if they believed that raising awareness of future generations at a young age regarding health and environmental issues might lead them to further integrate insects in their diet, 82% agreed and 8% didn't. Regarding the introduction of edible insect farms in controlled environments within cities, 81% agreed to be in favor while 6% disagreed. Next, 85% did and 3% didn't believe that valuing clean organic residues with insects represented an interesting complementary process to reducing food waste and composting organic residues. Finally, when asked if they would be open to the idea of rearing their own edible insects at home, 23% of respondents answered positively (Figure 2).

Figure 2. Respondents' openness to rear edible insects at home



Tastings results

Products and respondents

Four edible insect products were used for the tastings: (1) whole unflavored dried mealworms; (2) whole seasoned dried crickets; (3) homemade whole-grain savoury crackers (containing 20% powdered mealworms); and (4) processed sweet-flavored energy bars (containing 10% powdered crickets). Each of these products were farmed and processed locally. Due to the absence of savoury processed insect products on the local market at the time of performing tastings[11], crackers were home baked[12] specifically for this activity. Such a variety of insect products make it possible to assess consumers' preferences in terms of appearance, smell, texture, and taste (i.e. crickets versus

[11] Insect-based chips were expected to launch in December 2020, but the manufacturer encountered production delays.

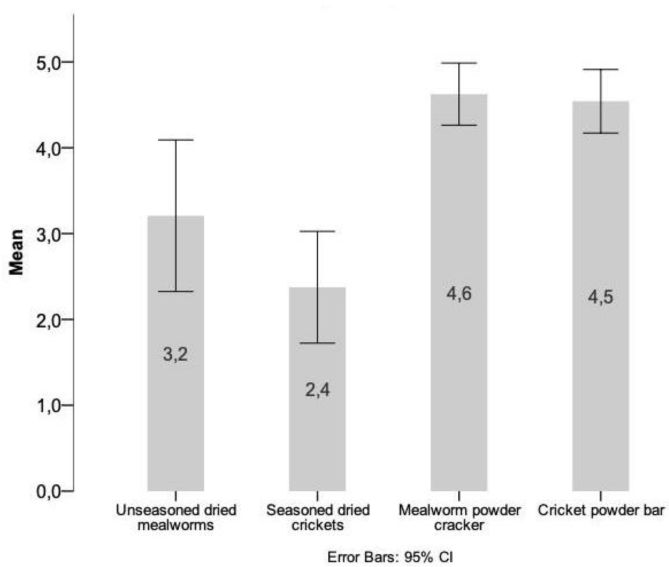
[12] Ingredients (20% sunflower seeds, 20% pumpkin seeds, 20% powdered mealworms, 13% sesame seeds, 13% chia seeds, 13% flaxseed, salt, and water) were mixed, spread evenly on parchment paper, and baked for 40 minutes at 150°C.

mealworms, visible vs processed, homemade vs industrial, 10% vs 20% and 100% insect content, crispy vs soft, unseasoned vs seasoned, and sweet vs savoury).

The group of tasters selected was composed of six women and six men, averaging 37 years old (standard deviation or s.d. 7.6). Ten of them had already experienced eating insects before (mainly mealworms and crickets, either whole or processed) but none of them were considered regular insect consumers (i.e. eating insect products at least once a week).

Organoleptic features
Tasters rated the appearance of processed insect products (PIP) significantly higher than that of whole dried insects (P<0.001; Figure 3). PIP were the only products described as "appealing", although some also characterized the cricket powder bar as "unappealing" – mainly due to their inability to visually identify the ingredients composing ultra-processed products such as that one. They thought the bar seemed like a very rich product, which should be used especially when needing an energy boost (i.e a functional rather than a hedonic foodstuff). Therefore, chances are that it would most often be consumed outside of the house, and less likely on a regular basis. However, some believed that performing physical activities might also remember them to grab a bar, whereas other products are more likely to be forgotten in kitchen cabinets.

Figure 3. Taster's average ratings for sampled products' appearance

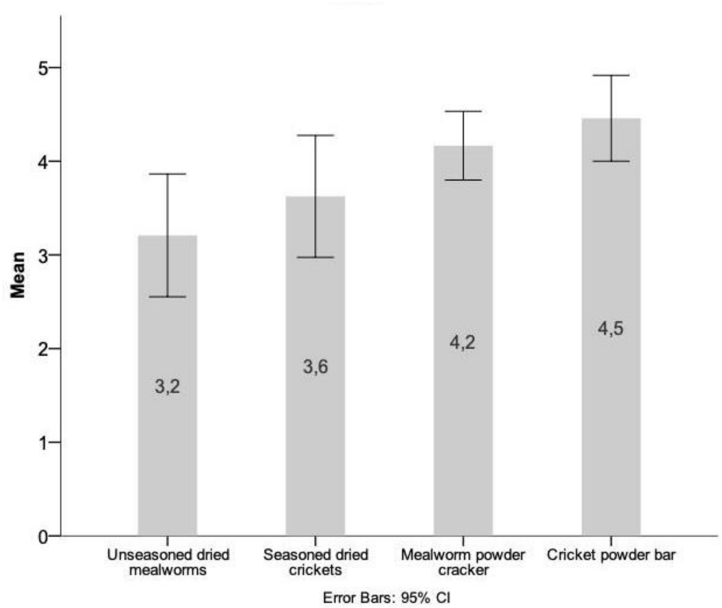


The visibility of the seeds composing the crackers was found to make the product seem more natural and nutritious. Tasters thought of it as being a healthy snack that can be consumed both at home and at work. Many found it would be a great appetizer when having friends or family over (i.e. prone to commensality) as it does not require preparation, it is easy to store and to share, and it can be a good conversation starter – triggering interesting discussions about entomophagy and food-related issues.

As for whole insects, tasters identified a visual preference for mealworms, which they described as homogeneous, light, translucent, and intriguing. Their translucent aspect was largely appreciated, as seeing mealworms' empty shell suggested a crispy rather than viscous internal texture. In comparison, crickets were characterized as big, harder, dark, dense, and intimidating. Some tasters were disgusted by being unable to predict the internal texture of the insect as well as both distinguishable (e.g. head, eyes) and absent (e.g. legs) body parts.

Seasoned dried crickets were ranked higher than unseasoned mealworms for smell, although not significantly (P=0.640; Figure 4). Most tasters found it hard to describe the smell of unseasoned dried mealworms, although some of them were able to identify earthy and roasted odors. Many thought crickets were more balanced, as seasoning took over the unfamiliar smell of completely natural insects. Seasoned insects were found to smell like chips, which tasters thought was a good fit for such a crispy product. One of them thought that this correlation helped associate the product to snacking occasions, making it less confusing as to how and when it could be eaten.

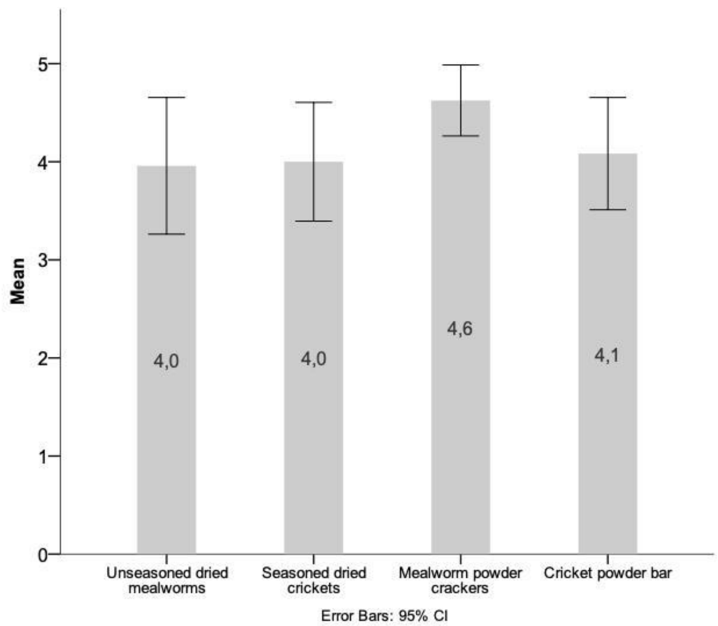
Figure 4. Taster's average ratings for sampled products' smell



Tasters found PIP to have a significantly better smell as compared to unseasoned dried mealworms (P=0.004). None of them could recognize the insect smell in processed products, which didn't seem to bother them. In fact, the protein bar – being described by most tasters as having a pronounced artificial smell – was ranked the highest amongst all four products, perhaps as it could more efficiently take over the unfamiliar insect smell.

All of the four products tested were associated with a generally highly appreciated texture (Figure 5; no statistically significant difference in scores). Compared to PIP, whole insects were found to benefit from a crispy texture – provided by insect dehydration process, which allows to enhance their shelf life. Crispness appears as the most interesting organoleptic characteristic identified by participating tasters. Mealworms were described as having a pleasant mouthfeel due to their airy and crumbly feeling (some participants described it as "funny"). Crickets were found to be rather dense and crunchy, with a pronounced tendency to get stuck in between teeth. For both of the whole insect products, tasters identified important temporal changes in texture during mastication, going from crispy or crunchy to dry and pasty (change was mentioned happening faster for mealworms than for crickets), which left a rather unpleasant feeling in the mouth. Participants thus found it necessary to rinse their mouth with liquids pretty much after every bite they were taking.

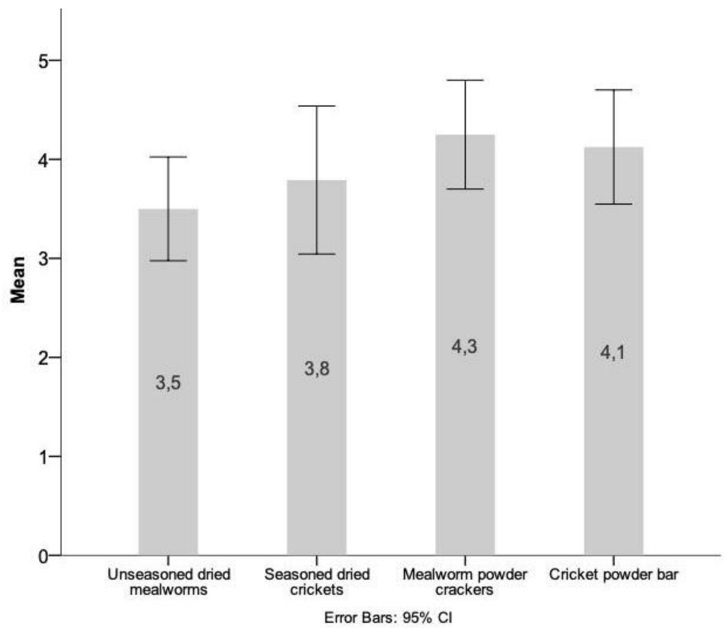
Figure 5. Taster's average ratings for sampled products' texture



As for PIP, tasters believed that the textures of both insect products they were presented with were perfectly adequate (i.e. crispy for savoury snacks and soft for sweet snacks). They thought crispy products were more pleasant to eat and also more addictive. Additionally, many suggested that insect crackers would be even more enjoyable if accompanied with a dip.

Finally, none of the four products tested showed a statistically significant difference in scores for taste (Figure 6). Unseasoned dried mealworms were described as having a light, roasted, and earthy taste, with flavors found to evoking nuts, mushrooms, and popcorn. As seasoning was found to completely take over the subtle taste of insects, participants were unable to distinguish any difference in taste that could be attributed to the type of insect used in the products they were presented with (crickets and mealworms). Seasoning (salt and pepper) was found to add a brief umami flavor that quickly disappeared, leading tasters with the desire to quickly take another bite. However, tasters thought unseasoned insects might be easier to pair with other ingredients, whether they would be used as topping on various dishes or powdered and incorporated in shakes or baked goods. Unseasoned insects were thus thought more likely to be routinely integrated in familiar recipes.

Figure 6. Taster's average ratings for sampled products' taste



As for PIP, all tasters found it difficult to recognize their insect taste – especially for the sweet bar containing fewer than 10% insect powder, as compared to 20% for the crackers (in order to market affordable products, insect food processors often cut on expensive insect powder). PIP were also more prone to singular consumer preferences, tasters often criticizing their degree of either saltiness or sweetness (some finding it too high and others too low).

Comparing both PIP, tasters didn't seem to have any preference in taste for sweet or savoury insect-based product formulations. They thought both types of products were a good medium to incorporate powdered insects and that they could respectively satisfy different types of cravings. They didn't think seeing both sweet and savoury insect-based products on grocery store shelves would confuse them. However, many participants mentioned that if they were to start eating insects with the motivation of reducing their meat intake, they would find savoury recipes to be more appropriate.

Discussion

Socio-demographic comparisons of knowledge and acceptance towards entomophagy

The practice of eating insects appears now widely recognized amongst Canadians. The vast majority of surveyed respondents (93%) had already heard about it – although the fact that many respondents have accessed the survey via an article or a promotional video on the topic of edible insect consumption might skew these results. In comparison, a study with a similar sample size conducted in Australia (where insect consumption is/was traditionally practiced amongst various indigenous communities) identified that 68% of respondents were aware of the existence of entomophagy (Wilkinson et al., 2018). In that same study, only 21% mentioned having previously eaten insects, whereas almost half of our surveyed Canadians (49%) were in that same situation, though most mentioned consuming bugs only on rare occasions. As compared to other Canadians, French Quebeckers showed a greater awareness of the existence of entomophagy, its widespread traditional practice across the world, as well as its benefits as meat alternatives. Not only did they show a greater knowledge towards entomophagy, but they were also more likely to have already experienced eating insects – a practice that seems to have considerably expanded since 2016 amongst this same sociodemographic group (going from 50% positive responses in 2016 to 54% in the present survey – although important sociodemographic differences are observed between both these surveyed populations).

Despite important differences in gender and age distribution amongst the two surveyed populations (Can and QcFr), the analyzed data reveal no significant relation between these factors and respondents' prior experience with insect eating. This observation contrasts many previous studies, where differences have been observed as pertaining to gender asymmetry in food consumption – as gender often represents a significant category of social differentiation (Arganini et al., 2012; Dubé et al., 2005). As pertaining to entomophagy, whereas some studies have identified gender gaps in terms of acceptability (Menozzi et al., 2017; Ruby et al., 2015), others have found no significant difference between male and female respondents (Adámek et al., 2018; Megido et al., 2014). Respondents' past experience with insect consumption was rather found to vary significantly according to their province of residence. Interestingly, those living in British Columbia and in the Maritimes, followed closely by those living in Quebec, were more likely to have already eaten insects, as compared to those living in other provinces. Hence, respondents living in coastal regions seem to exhibit food habits closer to those of their respective Asian and European transoceanic neighbors (where insect consumption is more accepted than in the United States). Although a greater prevalence of Asian migration and tourism in the metropolitan BC area could provide a plausible explanation to that observation, the same hypothesis could hardly be applied to the other side of the country – where a greater geographic proximity isn't linked to a higher prevalence of European visitors as compared to the large urban centres of Montreal (QC) and Toronto (ON), which are served by regular intercontinental flights. Whereas residents of central Canada seem more in line with traditionally American food habits (i.e. not used to consuming insects), Quebeckers seem once again to manifest a culinary openness that appears more aligned with that of their European descendants, as noticed by Hénault-Ethier et al. (2020).

Amongst all respondents having already engaged personally with entomophagy, most had done it only once. However, the vast majority (92%) mentioned being willing to repeat the experience, which leads to believe that edible insect trials tend to trigger rather positive reactions. As compared to other Canadians, French Quebeckers showed a greater willingness to engage once again with insect eating, and more of them had already done it. They were also more likely to have regularized their insect consumption: since the 2016 survey, the proportion of weekly insect eaters amongst surveyed French Quebeckers jumped from 0% to 8%, while monthly consumers increased from 6% to 9%. Therefore, it seems to indicate a quite significant regularization of entomophagy as a common practice amongst this specific sociodemographic group within the past few years. This observation could be correlated to a greater availability of commercialized insect products in this primarily francophone province, as compared to the rest of Canada. Although no market analysis can corroborate this hypothesis for the moment, companies offering edible insect products are multiplying in Quebec, where insect farming and processing companies have regrouped to form an association[13].

[13] https://www.facebook.com/aetiqc

As for respondents mentioning having never experienced entomophagy, two thirds of them mentioned being willing to try it – with Canadians showing this time a greater openness as compared to French Quebeckers. This could be explained by QcFr being offered greater opportunities to try edible insect products, thus leaving a larger proportion of heavily reluctant respondents in the unexperienced category. Beyond the possibility that insect products might be more easily accessible in the province, this hypothesis might be supported by the immense popularity of insect tasting activities (*Croque-Insectes*, from 1993 to 2005, and having started again in 2017) offered by Montreal's *Insectarium*, a world-renowned insect museum. Additionally, it appears that 2016 respondents showed more willingness to try eating insects for the first time, as compared to QcFr in the present survey. In addition to the last postulate, a possible explanation could reside in the higher proportion of respondents over the age of 64 having participated to the present survey – a population segment whose food habits are much more entrenched, and thus harder to alter.

Assessing respondents' motivations and barriers towards entomophagy

Comparing respondents' motivations for either eating or refusing to eat edible insects can help provide an overview of vegetarians' acceptance towards entomophagy. Of those having no prior experience with insect consumption and showing no willingness to try it in the future, 22% listed being vegetarian as a contributing factor. In comparison, amongst those mentioning being willing to consume edible insects in the future (whether for the first time or not), only 6% mentioned being vegetarian when they were asked whether or not considering edible insects as a potential meat replacement in their diet. Hence, a much lower proportion of vegetarians (and possibly including vegans) was identified amongst respondents showing openness to insect consumption as compared to those being unwilling to try it. Even amongst meat eating respondents, the vast majority (84%) didn't agree to consider edible insects as meat replacement in their diet. Therefore, positioning edible insects as an alternative to conventional meat doesn't appear to likely resonate strongly with most consumers. However, further investigations should be carried in order to adequately assess the barriers and motivations of vegetarians, vegans, and flexitarians for eating or refusing to eat edible insects.

Respondents having already experienced consuming edible insects found personal factors to be their main motivational drivers ("curiosity" and "personal challenge" respectively ranking first and second, although "ecology" wasn't far behind). However, as we cannot assess how long ago these factors have influenced respondents in their past experience with entomophagy, assessing the motivational drivers identified by the respondents that had never eaten insects but mentioned being willing to do so might allow us to better assess consumers' current motivations for eating edible insects. These respondents were found to be motivated by different and broader ranging factors (i.e. respectively "ecology", "curiosity", "animal welfare", and "health"). The higher relative importance attributed to all of these factors seem to indicate that consumers are now more conscious than they once were as regarding to the wide-ranging benefits of edible insects as an alternative foodstuff – possibly reinforced by an increased general food awareness regarding the social, environmental, and health consequences of their diet.

As for the respondents identified as being completely closed to insect consumption (having never tried it and mentioning not being willing to do so in the future), analyzing their responses can provide crucial information regarding the main barriers preventing the normalization of entomophagy as a common dietary practice amongst Canadians. The main factors explaining their reluctance towards insect eating were found to be linked to the appearance and texture of edible insect products. Other relatively important factors were respectively their fear of getting sick, mistrust regarding the origin of such products, and their taste, followed by the lack of insect farming and processing standards. Availability and price were found to be insignificant factors for trying edible insects – which isn't surprising as these factors mainly come into play only once insect products are adopted and consumers are willing to engage in repeated purchase.

Comparing stated and tasted preferences for edible insect products

Hence, appearance and texture were identified in surveys as the most important product attributes building consumers' reluctance towards edible insects, whereas respondents didn't seem to expect the taste of insects as being such an unpleasant characteristic. This observation was only partly validated by the participants partaking in the tastings, having also indicated a visual preference for products containing insects in an indistinguishable form (powdered or crushed). Although tasters found whole dried insects indeed less appealing than processed ones, they also commonly described them as being "*not as disgusting as expected*" (as supported by the fact that all products marked an average score higher than neutral for appearance). As for their texture, tasters were positively surprised by whole dried insects, giving them a score of 80%, which was quite similar to that of the processed products they were presented with. Hence, consumers seem to be largely misled regarding the sensory expectations that are building their reluctance towards edible insects.

Our tasting results support the observations made by Sogari et al. (2018), namely that: (1) edible insects' appearance and texture are identified by consumers as stronger barriers than taste (and smell, in our case); and (2) taste exposure seem to have a positive impact on the sensory-liking of edible insect foods amongst participants – unanimously supporting the appropriateness of most insect products they were offered. However, our findings are in opposition with other studies where the expected taste of insects appeared at the very top of the main predictors of consumers' willingness to try them (Hartmann et al., 2015; Wilkinson et al., 2018). Moreover, while integrating insects with familiar ingredients had already been found to increase their perceived edibility (Shelomi, 2015), tasters in the present study thought that pairing insects with other ingredients also helped improving their overall organoleptic properties (i.e. their appearance, smell and taste, while overcoming their dry and pasty mouthfeel resulting from mastication).

Surveyed respondents mentioned having a higher preference for whole dried crickets as compared to mealworms, but didn't show any preference for any of those once in a powdered form. Hence, respondents expected crickets to be more appealing and/or to better appreciate their texture (in the whole dried form), but they didn't expect any preference regarding smell and/or taste (in the powdered form). However, when exposed to actual insect products, tasters found mealworms more appealing than crickets in their whole form, while both were found to reveal a similarly appreciated texture (smell and taste were both found to be largely influenced by the presence or absence of seasoning). As they had difficulties identifying any particular insect taste in either seasoned or processed products, tasters couldn't identify any preference for the taste of crickets or that of mealworms, so it is a question that is worth further investigation. Although some tastings have already been carried to assess consumers' sensory liking for varying insect species (Hartmann & Siegrist, 2017; Mishyna et al., 2020), very few have attempted to compare their appreciation for these two most commonly farmed insect species intended for human consumption (Megido et al., 2014).

Additionally, analyzed survey results had identified a slight preference amongst consumers for savoury insect preparations, which couldn't be validated during tastings – perhaps biased by the fact that the savoury crackers contained twice as much insect flour as the sweet bars did, which can alter the sensory liking of the products being tested (Osimani et al., 2018). Additionally, the specific flavor of the sweet bar being tasted by participants (i.e. banana and chocolate) might have influenced their appreciation of the product (Adámek et al., 2018**)**. Although tasters indeed found savoury recipes to be more appropriate for those seeking out meat alternatives, sweet product formulations containing powdered insects were also said to be totally appropriate. Moreover, although surveyed participants largely agreed that they would give great importance to the traceability of insect products before consuming them, very few of the tasters asked any questions about the origin of the insect products they were offered. As tasters' attention was mainly focused on overcoming their psychological barriers for edible insect products, it might have contributed to tossing aside their other preoccupations. Hence, such traceability concerns might be more likely to surface at the time when consumers are at the phase of purchasing insect products.

Finally, three quarters of surveyed respondents believed that edible insects deserved a place in grocery stores, also predicting that entomophagy will keep growing in North America. An even larger proportion believed in insect farms as an interesting way to upcycle organics and were also in favor of seeing insect farms implemented in cities. If about a third of surveyed respondents aren't yet convinced that humans should eat more insects, they largely believe that youngsters might potentially be more likely to integrate insects in their diet. However, it appears that mealworms and crickets aren't yet considered friendly flatmates for Canadians – although the idea of domesticating edible insects at home charmed roughly a quarter of our respondents. Hence, more work remains to be done before their crucial role in maintaining functional ecosystems while providing palatable and nutritious foodstuffs is fully recognized, after which they might reach the privileged social status that yet only bees have been crowned with in the insect world – leading to the increased desire of their presence in private backyards, in public gardens and on corporate rooftops.

Conclusion

The present study allows for a better evaluation of the pace at which edible insect products are gaining interest amongst French Quebeckers as a specific geographical and sociocultural consumer group. A cross-cultural comparison with other surveyed Canadians also helps better assess French Quebeckers' specific characteristics in terms of knowledge, practice, motivations, preferences, and concerns towards entomophagy. Moreover, its multidimensional approach – integrating insect product tastings, although in a rather limited diversity and using a narrow sample size – provides a better understanding of French Quebeckers' preferences for such food products. Indeed, as our mind attempts to predict insect attributes based on available extrinsic cues, it often falsely guides us in assuming inadequate sensory expectations – which persist until we are given the opportunity to get a true sense of their true organoleptic features.

Besides developing further cross-cultural comparisons, future research should attempt to observe consumers' preferences for more diversified insect-based food preparations. It should also try to assess the consequences of eating contexts on consumers' appreciation for insect products – as mentioned by Sogari et al. (2018). Moreover, it could try to assess the role played by marketing elements, namely the impact of informational stimuli (e.g. brand names, slogans, rational and hedonic arguments conveyed) on consumers' affective, cognitive, and behavioral reactions. According to the present survey, potential insect consumers might be attracted by messages focusing on product novelty as well as on their related benefits for the environment, human health, and animal welfare – the latter being rather rarely used as a marketing message to promote edible insect products. However, these hypotheses remain to be validated. Such future investigations could include interviews with leading companies marketing edible insect products, which could help draw interesting parallels linking marketing decisions with consumers' purchasing responses.

Finally, both beliefs on which participants most widely agreed regarding the future of entomophagy pertained to: (1) the reluctance towards insect consumption being easier to overcome for youngsters, whose food habits are much less entrenched; and (2) the relevance of attempting to upcycle organic by-products with insects in order to reduce food waste. Whereas the former statement will be the subject of the next chapter, the following one will delve into avenues to implement circular economy practices in insect farms and will attempt to assess the economic and social benefits that it could generate.

Foreword to Chapter 4

Psychological barriers are largely responsible for dictating Westerners' aversion towards edible insects. As youngsters have been less exposed towards socio-cultural constructs and as their food habits are less entrenched, they might express a greater willingness to try edible insect products.

As part of a *Mitacs*-funded internship with the urban beekeeping company *Alvéole* (see Appendix C for project description) and in partnership with *Les Amis de l'Insectarium de Montréal*, I took part in a pilot project aiming to implement pedagogical insect farms in two high schools situated in the Montreal suburbs. These small moveable farms would allow fourth-grade students to get familiarized with cricket or mealworm farming. With the help of professors partaking in the project – and after obtaining ethical clearance (see certificate in Appendix K) – I asked participating students to complete surveys aiming to assess their initial attitudes towards edible insects and its evolution over the course of these activities.

After the first year of these projects, I decided to focus my attention on the school with the largest number of participating students, as activities were repeated for three consecutive years. The following chapter provides crucial insights on the importance of focusing on youngsters in efforts to support the practice of entomophagy in Western countries. It is intended for publication in the scientific journal *Appetite*.

Chapter 4: Targeting youngsters as agents of change for an entomophageous future

Introduction

In order to allow future generations to thrive on this planet, food production systems that support both food security and sustainability will have to play a more central role in political agendas. In the past decade, the potential role of edible insects in helping support such issues has become increasingly recognized (Halloran et al., 2018). Although entomophagy (i.e. insect consumption) is a common practice for about a quarter of the world's population (van Huis, 2016), such a habit requires in most cultures a disruption in mental categorizations. Many Westerners are familiar with insects, but perhaps not as ingredients to incorporate into their diets. As a radically new products that challenge traditional cognitive patterns, edible insects in such cultures thus represent discontinuous food innovations (Robertson, 1971).

The successful dissemination of these innovations depends largely on consumers' imitation behavior (Rogers, 2003). Hence, due to the enhanced curiosity and interest of some towards the active participation of their first users (i.e. innovators; Kleyngeld, 1974), edible insect products could become increasingly popularized by simply spreading their use through contagion. Since youngsters have a strong influence over their peers and family members, tactics designed to train future entomophagists may prove particularly promising. Youngsters are responsible for more than half of all new products entering their households (Brée, 2012), and they influence up to 80% of their family's food budget (Hunter, 2002). Therefore, efforts focusing on youngsters in order to accelerate the widespread adoption of entomophagy might prove highly effective in quickly altering social representations, perhaps eventually leading to the mainstream acceptance of insects as an actual foodstuff. Moreover, since youngsters' eating habits are less entrenched, they often tend to be less reluctant towards new foods (Tuorila et al., 2001). As food aversions and preferences tend to remain relatively stable during adulthood (Rigal, 2010), it appears important to alleviate consumers' reluctance towards entomophagy at a young age.

When confronted with the ecological, social, and nutritional benefits of edible insects, consumers face a significant cognitive dissonance (i.e. an incompatibility with their own dietary preferences). The dissonance is especially strong for insects, as they reach all three reasons for food refusal: they simultaneously evoke aversion (fear mixed with anxiety), danger, and disgust (Rozin et al., 2008). First, aversion is typically linked to food neophobia, a cognitive reluctance towards unknown foods as a psychological defence mechanism against poisoning (Martins & Pliner, 2006). As for danger, it is linked to insects being commonly and traditionally associated with devastated crops, decaying food, unwanted domestic intruders, and carriers of diseases (Looy et al., 2014). If some insects can indeed be toxic, over 2,000 species are known to be edible for humans (van Huis et al., 2013). In fact, due to their extremely rich nutritional profile (often compared to conventional meat; Payne et al., 2016), some farmers even grow crops with the main goal of attracting and harvesting insects rather than the crops themselves (FAO, 2010). Finally, disgust can be described as an irrational primary emotion that manifests itself in response to associations most often dictated by prevailing cultural norms (La Barbera, 2018). Indeed, beliefs associated with the nature or origin of food are largely driven by social constructs (Haidt et al., 1994). They can create strong reluctance towards unfamiliar products. Hence, our reluctance towards edible insects is both innate and acquired, in the sense that it is influenced by biological factors and cultural heritage as well (Fischler & Chiva, 1985). The latter is constructed mainly during childhood and adolescence, influenced by the various communities of belonging to which individuals have been grafted (Chiva, 2011).

As revealed by Lewin (1943) – largely responsible for popularizing studies pertaining to group dynamics (Borek & Abraham, 2018) – resistance to change stems from the fear of deviating from standards dictated by one's social circle. Therefore, entomophagy promotion could be facilitated by group-based actions, such as carrying discussions and other activities aiming to generate changes in collective behavior. According to *social cognitive theory*, learning that occurs in a social context and supporting reciprocal interactions and dynamic experiences amongst participants emphasizes external and internal forces leading to acquire self-efficacy and collective agency, which can prove successful in maintaining behaviors (Bandura, 1986). Although many studies have proposed more detailed processes of group dynamics leading to achieve behavioral changes amongst participants (Bartholomew et al., 2016; Gillies & Ashamn, 2003; Michaelsen et al., 2002), the three phases initially identified by Lewin (1943) offer a very general overview that is still recognized nowadays and forms the basis of most contemporary theories : (1) the reflection leading to the abandonment of initial behaviors; (2) the experimentation with new practices; and (3) the integration of new habits.

Following the *theory of planned behavior*, behavioral change can be achieved by increasing one's motivational drivers while developing his/her sense of ability (Ajzen, 1991). *Critical food pedagogy* is an approach aiming to address the impacts of dietary choices on human health, social justice, and ecological sustainability, while recognizing the components inherent to sustainable food systems (Sumner, 2015). Following such an approach might help more efficiently communicating the benefits associated with entomophagy, which has been shown to positively affect consumers' trial intent (Verneau et al., 2016). Beyond enhancing motivational determinants through knowledge sharing, addressing possible dietary alternative practices can help generate a greater sense of empowerment (Contento, 2015). Avoiding moralistic food teaching, embodied pedagogical learning combines thought with action and involves the training of specific capacities (Flowers & Swan, 2012). *Farm to School* programs – an integrative praxis combining *critical food pedagogy* with the acquisition of applied farming skills – have been found particularly effective in generating behavioral change (Bontrager, 2014; Moss et al., 2013). They have namely been associated with a successful decrease in participants' neophobia, an increase in their self-efficacy regarding the ability to make mindful food choices, and an alteration of social norms regarding (in)desirable foods (Koch, 2015). According to Share & Stewart-Knox (2012), the sensitive period during which unhealthy habits have greater potential to develop and when nutrition education may prove the most useful is between the age of 14 and 17.

In order for Westerners to eventually perceive insects as an actual foodstuff, strategies aiming to overcome reluctance must imperatively be put forward, aiming to modify individual and social mental representations. Although marketing strategies can help alleviating such consumer-level barriers (Marquis et al, 2020), exposure and familiarization have been identified as avenues that can help further overcoming reluctance towards edible insects (Tan et al., 2015). Pedagogical edible insect farming activities in schools hold the ability to create enjoyable learning environments where food and nutrition issues can be addressed, while providing knowledge about how to farm and cook with insects. Such activities centered on nutritional and even sensory education – supported by enhanced exposure and trial opportunities – could lead to the successful recognition of the benefits and palatability associated with insects, while possibly even overturning reluctant behaviors and increasing trial willingness amongst youngsters (Martins & Pliner, 2006; Reverdy et al., 2008). Due to researchers facing specific challenges and dilemmas when involving young subjects in their investigation (Best, 2007), there is a gap in the applied scientific literature on the benefits of involving youngsters in strategies aiming to support the growing popularization of entomophagy.

Materials and methods

The project

Between February 2018 and January 2020, 662 fourth-grade high school students (15-16 years old) divided into three cohorts of a science and technology program took part in a pilot project. The participating school was situated in the Montreal (Quebec, Canada) suburbs. At the beginning of the project, students attended a 30-minutes presentation about the potential of edible insects in promoting a sustainable diet and their ability to fight food waste by allowing the upcycling of certain types of organic residues. During the following weeks, these students' science and technology teachers led a series of workshops focusing on insect rearing methods to introduce students with basic notions of insect biology, including their nutritional and environmental needs as well as their reproduction cycle. Meanwhile, students had the opportunity to engage with insect farming in class over a three-month period. The first and second cohorts had to take care of small cricket farms (provided by the partner organization that helped launch the project, *Les Amis de l'Insectarium de Montréal*) while the last was offered the opportunity to raise mealworms (the small mealworm farms were provided by the Montreal-based insect farm *TriCycle*), thus allowing to perform both time-based and type-based analyses. At the end of the project, professors had organized tasting activities, so students that were willing to try insect-based products were given the chance to do so, provided that they had obtained parental approval – since it is believed that people allergic to crustaceans and house dust mites might also react to insects (Verhoeckx et al., 2014). This research was conducted in compliance with the ethical guidelines of *Concordia University* for research involving human subjects (certificate number 3007979, see Appendix K).

Questionnaires

Pre- (A) and post- (B) project surveys (37 questions at the beginning and 23 questions following the three-month projects) based on closed (yes or no), multiple-choice, five-point Likert scale (not at all; not really; undecided; yes, moderately; yes, very), and short answers were used for data collection. Some questions were derived from those used in a recently published Canadian survey that was co-authored by the same author of the present research (Hénault-Ethier et al., 2020). Online surveys (using *Google Forms*) were compiled in class by the students and supervised by their teachers. The questions were formulated in French, as the participating high school in francophone (see Appendix L for the questionnaires). The questions aimed to assess: (1) participants' initial degree of food neophobia (ten questions using a French adaptation (free translation) of Pliner and Hobden's (1992) *Food Neophobia Scale*); (2) their knowledge, acceptance, and behaviors towards entomophagy and insect farming; (3) the evolution over the time of the project of their acceptance towards edible insect; (4) their beliefs regarding the future of entomophagy; (5) their preferences for insect-based products; and (6) the influential impact they could have towards their peers.

Students also had to indicate their gender and country of origin, and they were given the opportunity to provide any additional statement. At the end of the surveys, participants were asked to respond to four questions regarding how they felt about the idea of having an insect farm in class (survey A) and how they found the experience (survey B). As an error occurred in the post-project survey forms (the last option of the five-point Likert scale was unavailable), these responses were discarded, as they could not be compared to those that had been selected in the initial survey.

Data analyses

The results compiled in *Google Forms* were first transferred in a *Google Sheets* / *Excel* matrix. In order to divide participants into five cultural groups, they were manually assigned a continent of origin, according to the country of origin they had mentioned in the survey. Then, responses to closed questions (yes or no) were changed for 1 and 0. Statistical analyses were performed using *SPSS* software: frequency & descriptive tables, independent samples t-tests, cross-tabulations (chi-squares), and one-way Anovas. Data were considered statistically different if $P<0.05$. Charts were also built using the same software. As the last question (additional statement) was an open one, responses were read and manually categorized according to the subsections of the present article. The most relevant or repeating comments are mentioned on the results section as supporting elements. Respondents' original answers in French can be found in Appendix M.

Respondents

Participation in the project was mandatory for all students registered in the science and technology program. The number of students in the three cohorts completing the initial survey were respectively 216 (62,9% females) in February 2018 (A1), 209 (67,6% females) in October 2018 (A2), and 237 (65,5% females) in September 2019 (A3). Thirteen students either didn't relate to any gender or chose not to disclose this information. In order to assess the effect that respondents' different cultural backgrounds could have on their attitudes and behaviors relating to entomophagy, they were grouped into five categories according to their country of origin: 72.8% were from Canada or the United States (CanUS, with only four US students), 7.3% from Asia, 6.5% from Africa (Afr), 5.9% from Europe (Eur), and 2.9% from Latin America or the Caribbean (LAC). The rest of them (4.7%) refused to answer this question. The number of students participating in the post-project surveys were 223 (63% females) in May 2018 (B1), 172 (68% females) in January 2019 (B2), and 221 (67.3% females) in January 2020 (B3). This time, 23 students didn't relate to any gender or chose not to disclose their gender. As surveys were answered in class, the number of respondents varies in the A and B surveys (662 vs 616 respondents, with one student group from the second cohort not completing the post-project survey due to a lack of time in class). The questionnaires did not allow to match respondents in the A and B surveys.

Results

Initial degree of food neophobia

In the survey A, ten questions (see Table 11) used a five-point Likert scale to assess students' degree of food neophobia (*Food Neophobia Scale*, or FNS). Rather than the original seven-point scale used in the FNS developed by Pliner and Hobden (1992), a five-point one was also used by Verbeke (2015) for the sake of simplification. Therefore, the maximum possible neophobia score for this survey was 50. The two questions (5 and 10) using the terms "ethnic" in their original 1992 formulation to qualify foods restaurants originating from other countries were translated into French using the word "*étrangère*", which connotation appears less disputable.

Table 11. Questions and participants' mean scores to the questions relating to food neophobia

Questions (R= reverse coded)	Mean	SD	Factor 1	Factor 2
1. I like trying new and different foods (R)	2.11	0.99	.786	.236
2. I don't trust unknown foods	3.11	1.13	.236	.749
3. If I don't know what is in a food, I won't try it	2.87	1.20	.028	.760
4. I like foods from different countries (R)	1.92	0.98	.761	.038
5. "Ethnic" food looks too weird to eat (discarded)	1.96	0.94	.412	.436
6. At dinner parties, I am ready to try new foods (R)	1.64	0.88	.693	.223
7. I am afraid to eat things I have never had before	2.37	1.20	.439	.636
8. I am very particular about the foods I eat	2.47	1.20	.617	.299
9. I will eat almost anything (R) (discarded)	2.67	1.29	.667	.319
10. I like to try new "ethnic" restaurants (R)	1.87	1.05	.809	.090

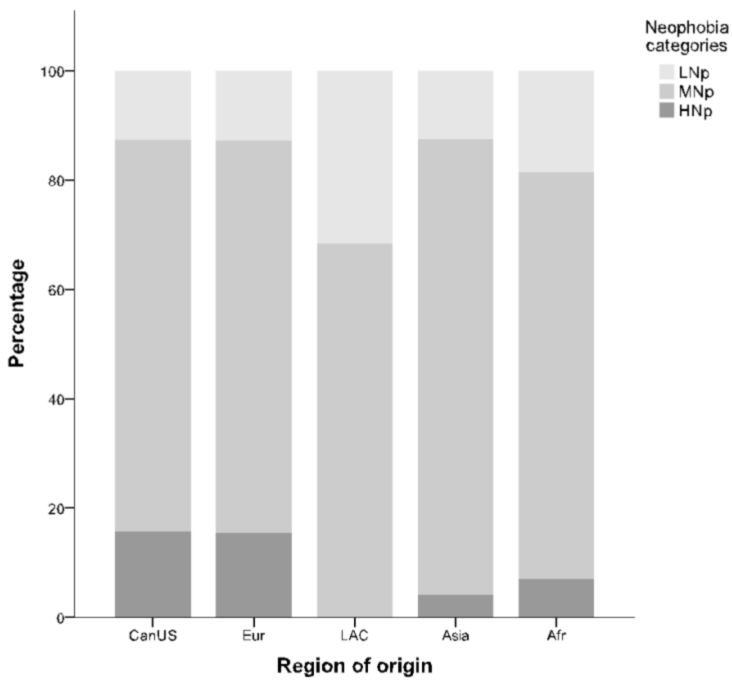
The FNS showed a Cronbach alpha value of 0.873, indicating a high degree of internal validity. Performing a factor analysis using the *Varimax* rotation method with a *Kaiser* normalization revealed that FNS questions could be divided into two factors: questions 1, 4, 6, 8, 9, 10 (factor 1, explaining 35.7% of the variance) and questions 2, 3, 7 (factor 2, explaining 20.4% of the variance). Question 5 was absent from both these groups as its factor was inferior to 0.5. A similar categorization of questions has also been observed by Olabi et al. (2009), who explained it by observing that the factors seemed to differentiate questions relating to "apprehension with regard to trying novel and *ethnic* foods" (regular questions) versus those relating to the "interest in trying new foods" (reversed questions) (Olabi et al., 2009). Indeed, questions 1, 4, 6, 9, and 10 have a reverse formulation, meaning that positive answers are linked to neophilia rather than neophobia. Therefore, these responses had to be reverse coded (answer 1 corresponding to 5 points, answer 2 to 4 points, etc.). While performing a cross-national comparison of people living in the U.S., in Sweden, and in Finland, Ritchey et al. (2003) decided to discard questions 5 and 9 as they thought responses could interfere with other variables (possibility of subjective interpretations and dietary limitations). Although these preoccupations do seem justified, the values we obtained after deleting these variables have been found to correlate strongly (r=0,986; P<0.001) with those of our full FNS questionnaire. All ten questions have therefore been maintained for the following analysis.

Data analysis revealed an average score of 22.92/50 (or 32/70), with a standard deviation (SD) of 7.16. When comparing female and male participants, no significant difference in their FNS score was observed (P = 0.806). As suggested by Pliner & Hobden (1992) in order to classify respondents based on their degree of neophobia, those showing a FNS score that was over the SD (> 30/50) were categorized as highly neophobics (HNp, 13.8%) while those showing a FNS score that was below the SD (< 16/50) were categorized as low neophobics (LNp, 13.6%), the remaining forming the mildly neophobics category (MNp, 72.6%) (Table 12). Although not quite statistically significant (P=0.054), the distribution of neophilia categories appears to vary according to respondents' region of origin (Figure 3).

Table 12. Representation of neophobia categories according to respondents' region of origin

Region		LNp	MNp	HNp	Total
CanUS	n	61	345	76	482
	%	12.7%	71.6%	15.8%	
Eur	n	5	28	6	39
	%	12.8%	71.8%	15.4%	
LAC	n	6	13	0	19
	%	31.6%	68.4%	0%	
Asia	n	6	40	2	48
	%	12.5%	83.3%	4.2%	
Afr	n	8	32	3	43
	%	18.6%	74.4%	7%	
All	n	86	458	87	631
	%	13.6%	72.6%	13.8%	

Figure 7. Visual representation of neophobia categories according to respondents' region of origin



> *"Due to my allergies, I am more fearful towards unfamiliar foods."*

> *"It would be interesting to integrate insects into our food culture :)"*

Knowledge, acceptance, and behaviors towards entomophagy and insect farming
At the beginning of the projects (survey A), three closed questions were asked to assess participants' knowledge towards entomophagy. When questioned about whether they had already

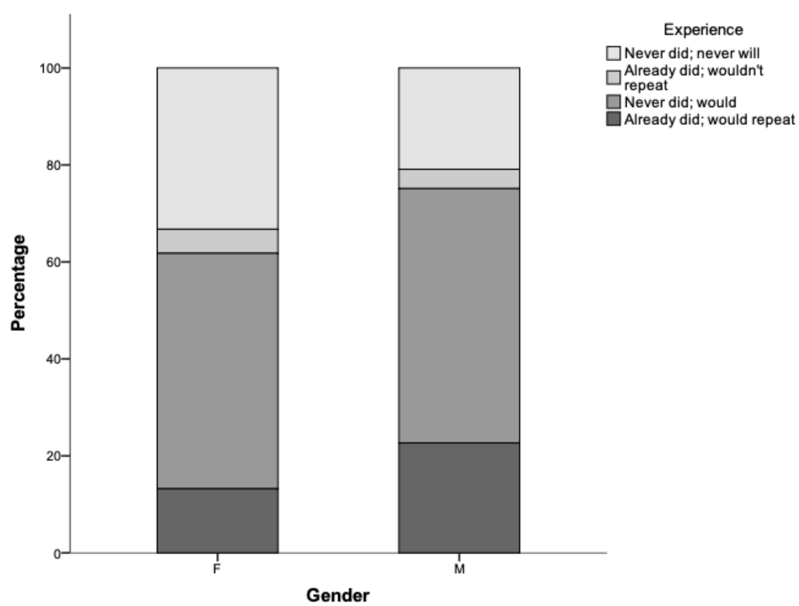
heard about the practice of eating insects, 87% of the respondents replied yes, which is lower than the 97% average previously assessed for French Canadian adults (Hénault-Ethier et al., 2020). Although 77% of them knew that insects represented a sustainable alternative to conventional meat, only 25% knew that entomophagy was a common practice in cultures representing about a quarter of the world population. No statistical difference was observed between the three participating cohorts (A1, A2, and A3).

As for their past experience and future intentions relating to entomophagy, 27% of male and 18% of female participants mentioned having experienced it already (Table 13 and Figure 8). Half of our respondents had never tried eating insects but declared being willing to do so. Significant differences (P=0.001) were observed between males and females, with males being more prone to have already tried eating insects while indicating a willingness to repeat the experience (23% versus 13%), and females being more likely to have never tried and to never intend trying eating insects (33% vs 21%). Students' country of origin didn't seem to have a significant impact on their past and predicted experience relating to entomophagy.

Table 13. Respondents' past experience and future intentions relating to entomophagy according to gender (survey A)

Experience & intentions	**F (%)**	**M (%)**	**All (%)**
1. Never did; never will	33.3	20.9	29.0
2. Already did; wouldn't repeat	5.0	4.0	4.6
3. Never did; would	48.6	52.4	49.9
4. Already did; would repeat	13.2	22.7	16.5

Figure 8. Visual representation of respondents' past experience and future intentions relating to entomophagy according to gender (survey A)

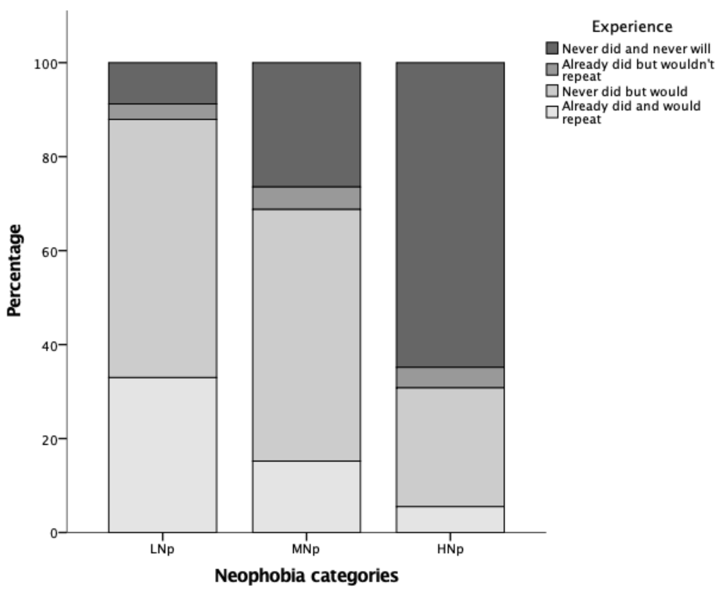


Students' degree of neophobia had a very significant impact (P<0.001) on their past experience and future intentions relating to insect consumption. Of HNp participants, 65% had never tasted insects and didn't intend to do so; whereas only 9% of LNp identified themselves as being in such a situation (Table 14 and Figure 9). Similarly, 33% of LNp had already tried edible insects and would repeat the experience, compared to less than 6% of HNp.

Table 14. Respondents' past experience and future intentions relating to entomophagy, according to their neophilia category (survey A)

Experience & intentions	LNp (n)	LNp (%)	MNp (n)	MNp (%)	HNp (n)	HNp (%)
1. Never did; never will	8	8.8	127	26.5	59	64.8
2. Already did; wouldn't repeat	3	3.3	23	4.8	4	4.4
3. Never did; would	50	54.9	257	53.5	23	25.3
4. Already did; would repeat	30	33.0	73	15.2	5	5.5

Figure 9. Visual representation of neophobia categories according to respondents' past experience and future intentions relating to entomophagy



When initially questioned about the motives why they would be willing to consume edible insects, the most popular reasons (corresponding to answers 4 and 5 on the Likert scale) were respectively "curiosity" (62%) and "ecological concerns" (62%), followed by "health" (56%) and "personal challenge" (56%), "ethical concerns" (54%), and "to be noticed" (8%). The average score given to each reason allows us to better differentiate the importance given to each factor (Table 15). Ecological (P=0.031) and ethical concerns (P>0.001) (e.g. practical reasons) were significantly more popular amongst female participants, whereas males were more tempted by personal or social factors, such as "curiosity" (P=0.043) and "to be noticed" (P=0.02). Only two of these factors ("health" and "personal challenge") are found to vary insufficiently to show a statistical difference between participants' gender (P>0.05).

Table 15. Relative importance of specified motives to consume edible insects (survey A)

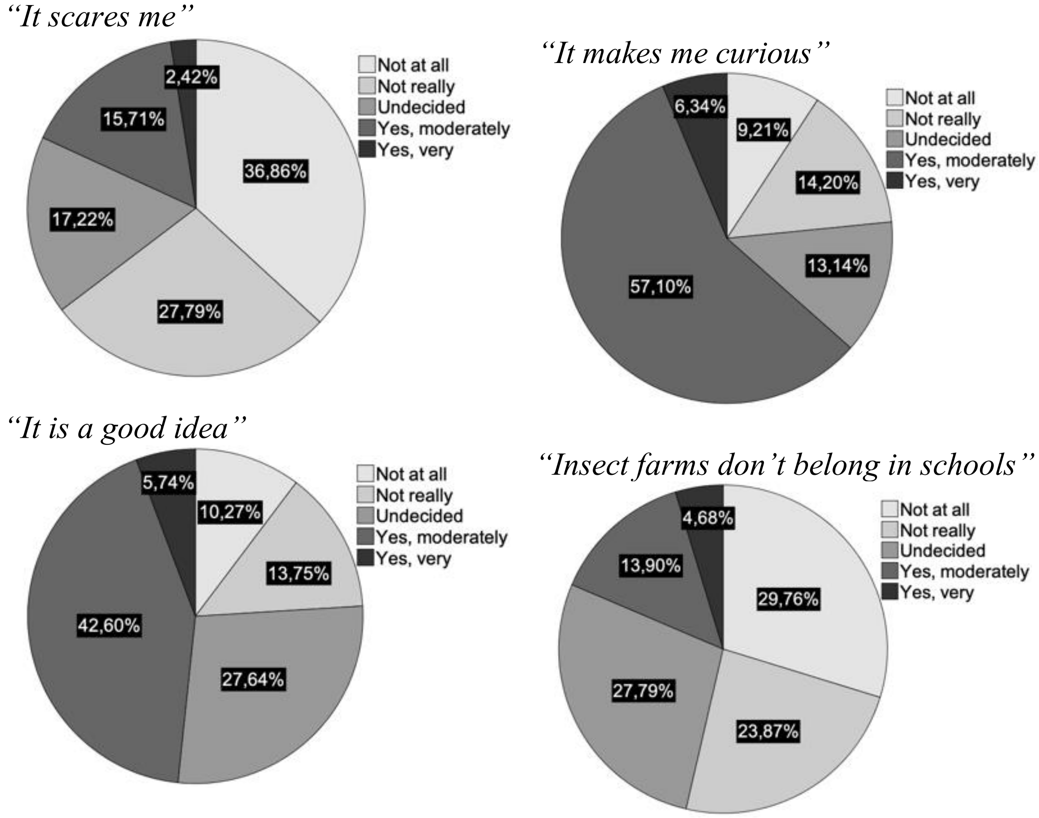
Factor	Gender	Mean	SD	F/M P*
Curiosity	F	3,41	1,323	
	M	3.63	1.354	
	All	3.49	1.337	0.043*
Health	F	3.47	1.185	
	M	3.32	1.252	
	All	3.42	1.210	0.134
Ecological	F	3.70	1.233	
	M	3.47	1.333	
	All	3.62	1.272	0.031*
Ethical	F	3.33	1.285	
	M	2.78	1.376	
	All	3.14	1.342	0.000*
Personal challenge	F	3.04	1.425	
	M	3.05	1.468	
	All	3.04	1.439	0.925
To be noticed	F	1.58	.971	
	M	1.79	1.106	
	All	1.65	1.024	0.020*

*Robust test of equality of means (Welch correction) performed when Anova P > 0.05

> "*I have a great phobia for insects. If I weren't afraid of them, I would be willing to eat them for my own health and for the environment.*"
>
> *"I hope we can compare insects to conventional meat in class on several levels, such as ecological, nutritional, gastronomic, and economic benefits."*
>
> *"I am a vegetarian and plan on becoming vegan, but if it has a positive impact on my health, I would be willing to give it a try. However, for me, killing an insect, a fish, a bird or any other animal is all the same, as they are living beings."*
>
> *"Are insects ethically a good option for vegans?"*

When participants were asked four questions in survey A regarding how they felt about the idea of having an insect farm in class, 18% were moderately or very scared (with 37% undecided), 63% were moderately or very curious (with 14% undecided), 48% thought it was a good idea (with 14% undecided), and 19% thought insect farms shouldn't belong in schools (with 30% undecided) (Figure 10).

Figure 10. Respondents' perception of having an insect farm in class (survey A)



> *"I've already farmed mealworms before. I found it not only educative but really fun (mine was named Arthur). I would really like to have an insect farm in my classroom."*
>
> *"I already consume cricket flour. I find GREAT the idea of having an insect farm in class."*
>
> *"I find that it would not make sense to eat (insects) as I am vegan and I already excluded other sensible living creatures from my diet. However, I would be curious to learn more about insect farming and its ecological impact."*

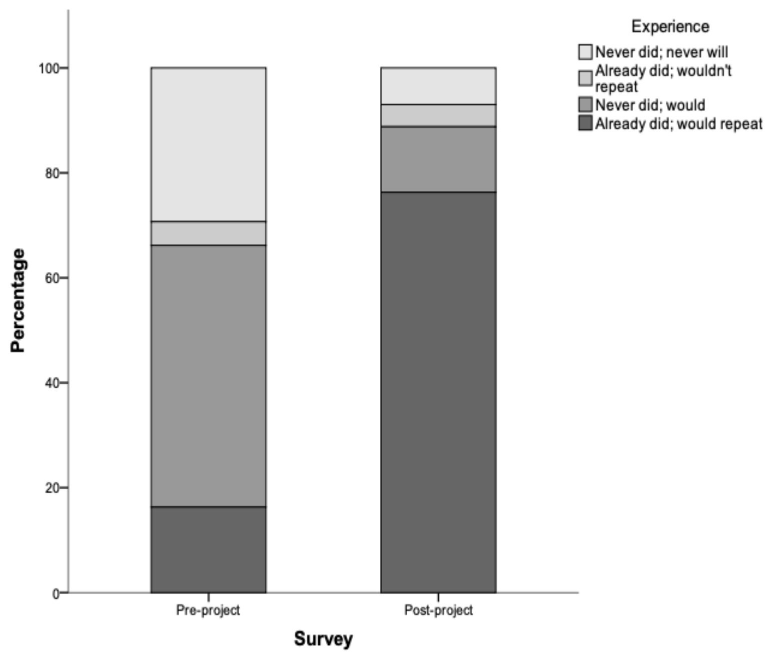
Evolution of acceptance and behaviors towards entomophagy

Post-project surveys revealed a great variation in students' experience and intentions towards entomophagy (as compared to pre-project surveys), showing this time no statistically significant variation between female and male participants (P=0.253). Over the course of the project (comparing surveys A and B), the proportion of participants that had already tried edible insects and would be willing to do it again rose from 13% to 76% for females, and from 23% to 80% for males; those that had never tried and never intended to try it dropped from 33% to 7% for females, and from 21% to 6% for males (Table 16 and Figure 11). In the pre-project surveys, females were 25% more likely than males to have already tried consuming insects without wanting to repeat it (5% vs 4%); in the post-project surveys males were 50% more likely than females to find themselves in the same situation (5.4% vs 3.6%). At the end of the projects, a total of 10% of the female and 11% of the male participants stated that they would not be willing to engage in edible insect consumption in the future; compared to respectively 38% and 25% prior to the projects.

Table 16. Evolution of respondents' past experience and future intentions relating to entomophagy, when questioned after the project

Experience		**F (%)**	**M (%)**	**All (%)**
Never did; never will	B	6.6	5.9	6.4
	var.	-26.7	-15	-22.6
Already did; wouldn't repeat	B	3.6	5.4	4.2
	var.	-1.4	+1.4	-0.4
Never did; would	B	13.8	8.9	12.1
	var.	-34.8	-43.5	-37.8
Already did; would repeat	B	76	79.7	77.2
	var.	+62.8	+57	+60.7

Figure 11. Visual representation of the evolution of respondents' past experience and future intentions relating to entomophagy



> *"I enjoyed eating (insects) and found out that it wasn't at all gross or scary."*
>
> *"I would appreciate another tasting opportunity, not with whole (insects) but in the form of flour."*

The motives that explain such a change in students' attitudes and behaviors seem to relate to many factors. The motivational factors that have gained significant importance ($P<0.001$) over the course of the project were respectively health and ecological concerns (for participants altogether). Ethical concerns (P<0.001) and curiosity (P=0.003) factors also gained significant importance for females (Table 17). Males were significantly (P<0.001) less inclined to do it as a personal challenge than they did in pre-project surveys, and both genders gave significantly (P<0.001) less importance to the motive of being noticed, which was already the less popular one in the pre-project surveys.

Table 17. Motivational factors to engage with entomophagy in surveys A and B, according to gender

Motive	Gender	Survey A mean	Survey B mean	Survey B SD	Survey B var. (%)	Survey B F/M P*	Survey A/B P*
Curiosity	F	3.41	3.7	1.504	5.8		0.003*
	M	3.63	3.58	1.607	-1		0.743
	All	3.49	3.66	1.540	3.4	0.393	0.033*
Health	F	3.47	4.01	1.215	10.8		0.000*
	M	3.32	3.78	1.437	9.2		0.001*
	All	3.42	3.93	1.298	10.2	0.055	0.000*
Ecological	F	3.70	4.17	1.221	9.4		0.000*
	M	3.47	3.87	1.487	8		0.003*
	All	3.62	4.07	1.324	9	0.014*	0.000*
Ethical	F	3.33	3.76	1.435	8.6		0.000*
	M	2.78	2.83	1.790	1		0.751
	All	3.14	3.44	1.625	6	0.000*	0.000*
Personal challenge	F	3.04	3.07	1.799	0.6		0.767
	M	3.05	2.41	1.938	-12.8		0.000*
	All	3.04	2.84	1.873	-4	0.000*	0.039*
To be noticed	F	1.58	0.86	1.396	-14.4		0.000*
	M	1.79	1.06	1.589	-14.6		0.000*
	All	1.65	0.93	1.466	-14.4	0.136	0.000*

*Robust test of equality of means (Welch correction) performed when P Anova > 0.05

> *"Insects are the way out for cutting meat."*

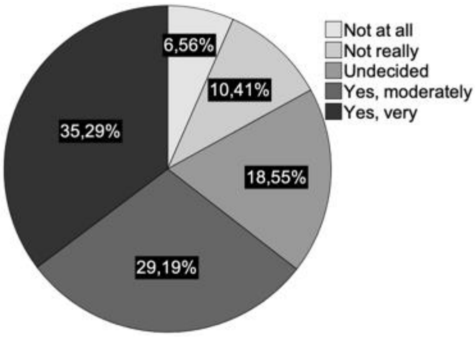
> *"We should talk about (entomophagy) more in order to save the fate of the planet!"*

> *"The population should be better informed so that they open up to the idea of eating insects. Especially if they aren't aware of all of their benefits."*

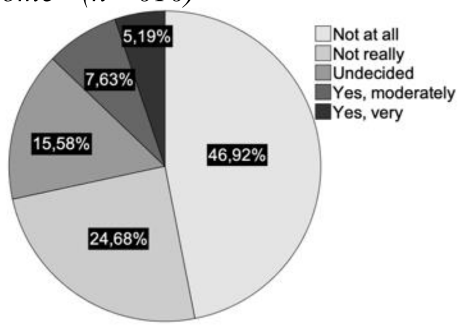
When students were asked about their appreciation of the project and their future intentions relating to insect farming, 64% mentioned they had been either moderately or very interested to learn more in class about insects and their farming (with 19% undecided) and 13% mentioned being open to the idea of raising insects at home (with 16% undecided) (Figure 12).

Figure 12. Respondents' appreciation of the project and future intentions relating to insect farming (survey B)

"I was interested to learn more in class about insects and their farming" (n = 442)



"I would be open to the idea of raising insects myself at home" (n= 616)



> *"It was very interesting to taste insects. Otherwise, I don't think I would have purchased insects just to try them."*
>
> *"It was a very interesting and innovative project! I hope to consume insects more regularly when they become more widely available."*
>
> *"I think that education about entomophagy should be compulsory in all schools as it is a great way to start saving our planet :)"*

Beliefs regarding the future of entomophagy

When asked a series of questions aiming to assess their beliefs regarding the future of entomophagy (surveys B), 96% of participants thought that insects could represent an advantageous nutritional choice over conventional meat (closed question), 83% that edible insects should be available in grocery stores, 75% that humans should eat more insects, 71% that more and more people will consume insects in North America, and 88% that we should feed more animals using insects (Table 18).

Table 18. Statements aiming to assess participants' beliefs regarding the future of entomophagy

	Not at all (%)	**Not really (%)**	**Undecided (%)**	**Moderately (%)**	**Very (%)**
I believe humans should eat more insects.	4.55	4.55	16.2	29.1	45.
I believe edible insects should be available at the grocery store.	2.9	2.4	11.5	24.4	56.
I believe more and more people will consume insects in North America.	3.2	5.2	20.8	38.5	32.
I believe we should feed more animals using insects.	1.3	1.9	8.3	17.9	70.

"I believe that over time, society will get used to eating insects and hardly anyone will be disgusted by them."

"I think more work should be done on overcoming people's mental block when they face bugs and find them repulsive, so that in the long run they no longer feel disgusted."

"I think it is good to raise our awareness now as I believe (entomophagy) will gain in scale and importance over the years. It should be considered as an innovative solution to fight climate change!"

"I really enjoyed this experience and I hope that we will find more insects in grocery stores in order to (...) consume them on a daily basis. More cookbooks should include insects (...)"

"Many people are afraid to try insects and to incorporate them into their diet because it is unusual for them. Even I, who claim to be open to the idea, am a little nervous about it. Creating advertisements, trial opportunities, and making them (more widely) available in grocery stores would greatly help to make people more comfortable and open-minded towards this practice."

Preference for insect-based products

In survey A, participants were asked about their preferences regarding the form(s) in which they would be willing to consume edible insects (whole, crushed, and/or powdered). Globally, participants declared having a preference for powdered and crushed insects, with powder being the most popular form. A much greater proportion of LNp participants selected crushed and whole insects as compared to MNp, themselves being more inclined to select these same insect forms as compared to HNp (Table 19). In contrast, powdered insects showed the reverse trend: they were more popular amongst MNp participants, and this preference was further enhanced amongst HNp. Such a difference relating to participants' preferences for insect products, according to the neophobia category in which they were grouped, was found to be significant for whole ($P=0.003$) and crushed ($P<0.001$) forms, but not for the powdered one ($P=0.455$).

Table 19. Preferred form(s) for edible insects according to participants' neophobia categorization (survey A, possibility to select many responses)

Form	LNp (%)	MNp (%)	HNp (%)	All (%)
Whole	37.4	23.3	16.5	24.3
Crushed	38.5	32.3	13.2	30.5
Powdered	61.5	65.4	70.3	65.6

"I think the only reason why I would refuse to eat bugs is because their appearance really turns me off. I might be more inclined to eat them if they were presented in a way that you couldn't distinguish them."

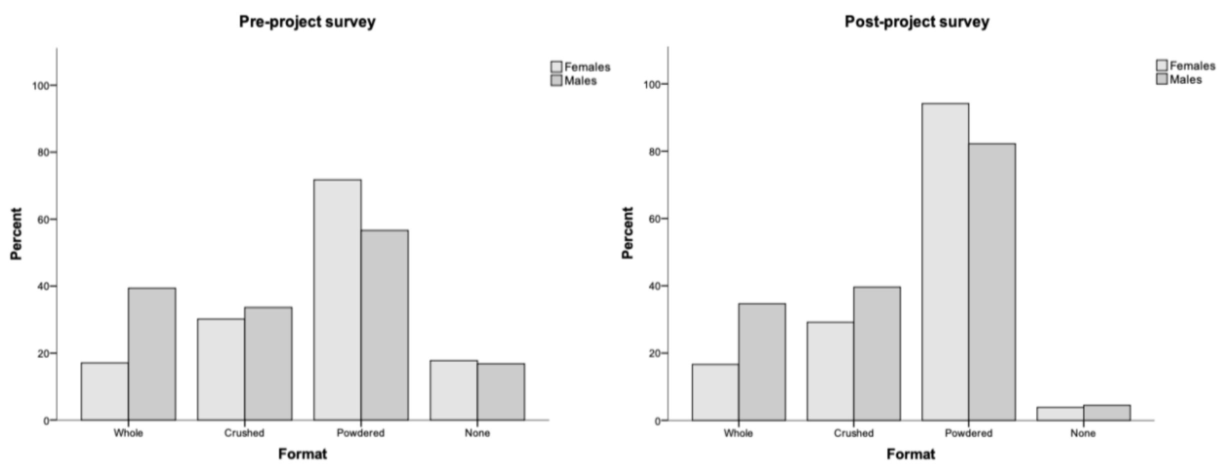
In survey B, participants were questioned once again about their preferences for insect-based products. Although in both surveys male and female participants declared a preference for powdered insects, females were found to have a significantly greater preference for them than males (P<0.001), themselves being much more willing to consume whole insects (P<0.001). In post-project surveys, a sharp decrease in the number of respondents choosing the answer “none”, and a sharp increase in those choosing the answer “powdered”, were observed amongst both genders. Their preference for “whole” and “crushed” insect forms remained relatively stable in both surveys (Table 20 and Figure 13).

Table 20. Preferred form(s) for eating edible insects selected in surveys A and B, according to participants’ gender

Form	**Survey**	**F (%)**	**M (%)**	**All (%)**	**F/M P***
Whole	A	17	39	24	<0.001*
	B	17	37	23	<0.001*
Crushed	A	30	34	31	0.36
	B	29	40	33	0.01*
Powdered	A	72	57	66	<0.001*
	B	94	82	90	<0.001*
None	A	18	17	17	0.762
	B	4	5	4	0.717

*Pearson’s Chi^2

Figure 13. Visual representation of the preferred form(s) for eating edible insects selected in surveys A and B, according to participants’ gender



In surveys A and B (after tasting activities were held), students were asked if they would rather tend to associate edible insects to sweet or to savoury recipe formulations. The average responses went from an average of 2.78 (slightly disagree) in survey A to 3.21 (slightly agree) in survey B. No significant difference was observed according to participants’ gender (P=0.252).

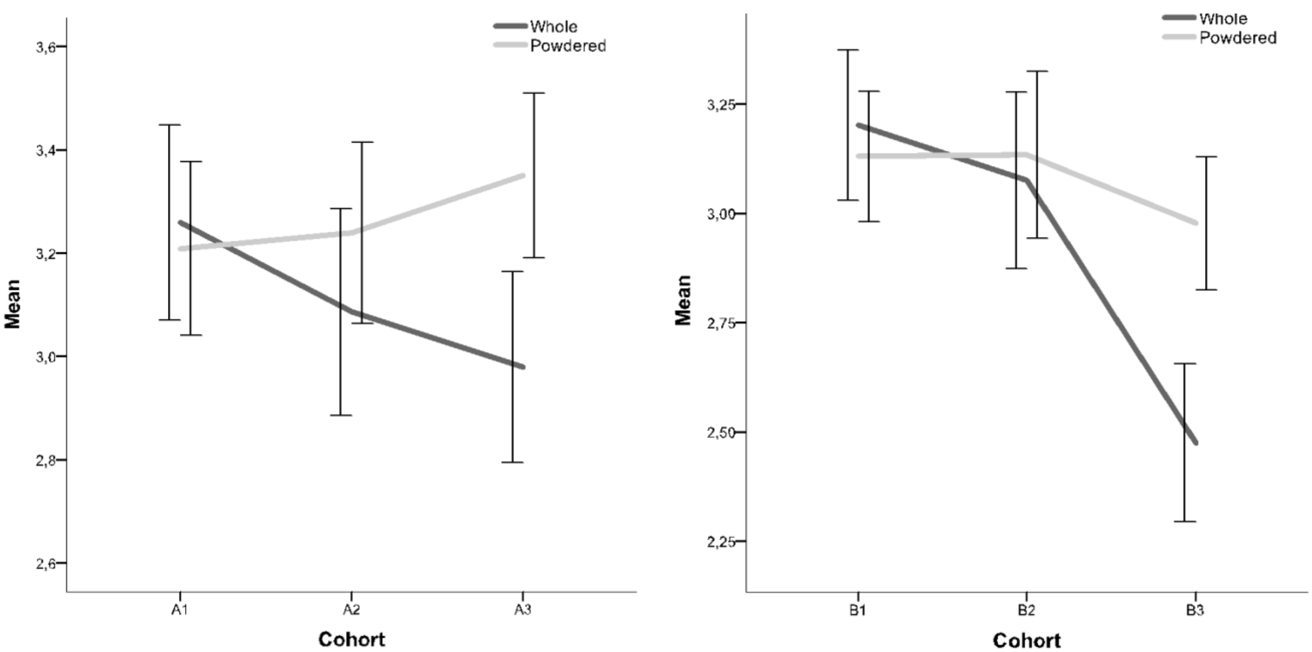
> *“I like barbecue-flavored insects.”*
>
> *“I think that we should focus on the nutritional aspect of mealworms’ rather than their taste, and that they should be served in recipes avoiding sugars and animal fats (...)”*

In both surveys, students were also asked if they would rather consume crickets than mealworms, and that for two different insect forms (whole and powdered). At the beginning of the projects (survey A), differences were found to be not significant, showing a slight preference for crickets, most especially in the powdered form. However, at the end of the projects (survey B), a significant difference can be observed (P<0.001) in the responses provided by both initial student cohorts (1 and 2, having engaged in cricket farming) with that of the last cohort (3, having farmed mealworms), but only as regarding their preferences for whole crickets (they didn't agree anymore with having such a preference), and not for the powdered ones (Table 21 and Figure 14).

Table 21. Respondents' preference for crickets (1 to 5 scale) divided by cohort (1 to 3) and survey (A and B)

Survey	n	Whole mean	Whole SD	Powdered mean	Powdered SD
A1	216	3.26	1.403	3.21	1.253
A2	209	3.09	1.468	3.24	1.282
A3	237	2.98	1.445	3.35	1.249
All A	662	3.10	1.442	3.27	1.260
B1	223	3.20	1.305	3.13	1.133
B2	172	3.08	1.346	3.13	1.270
B3	221	2.48	1.360	2.98	1.150
All B	616	2.91	1.374	3.08	1.179

Figure 14. Visual representation of respondents' preference for crickets (1 to 5 scale) divided by cohort (1 to 3) and survey (A and B)



"I prefer the taste of crickets and find them less disgusting as compared to other insects. I would rather eat them powdered, and I prefer when they are served in combination with other foodstuffs."

Student's influence on their peers

When comparing responses from the three student cohorts in survey A, a chi-squared test reveals a significant difference (P=0.03) regarding participants' past experience and future intentions relating to insect consumption. A multiple comparison test reveals that this difference is not present amongst both starting cohorts (A1 and A2), but only when these are being compared to the last participating cohort (P=0.001 when comparing A1 to A3, and P<0.001 when comparing A2 to A3). Amongst the last cohort, fewer participants declared having never tried and never intending to try eating edible insects, with a greater proportion of them being rather inclined to try it (Table 22).

Table 22. Participants' past experience and future intentions with entomophagy amongst cohorts (survey A)

	n	Didn't / wouldn't	Did / wouldn't	Didn't / would	Did / would	Compared to	Comp. P
A1	216	34%	5%	48%	13%	A2	.988
						A3	.001*
A2	209	34½%	5%	48%	12½%	A1	.988
						A3	.000*
A3	237	20½%	4%	53%	22½%	A1	.001*
						A2	.000*
All	662	29%	4½%	50%	16½%		

> *"You should (focus more on) educat(ing) adults, as they have a stronger influence on youngsters. I'm sure that (entomophagy) would become a growing habit in Quebec, if only households were made aware of all its benefits."*
>
> *"My dad is launching his own cricket powder project."*
>
> *"(This project) really changed my vision of insects! I strongly encourage talking more about it in schools!"*
>
> *"I tasted (insects)… not that bad finally! I even got my family to eat some without them knowing! Hahaha"*
>
> *"We should talk more about (insects) in class and get the students from all levels involved in this project in order to raise awareness at all ages."*
>
> *"Keep doing such conferences in schools because we are the new generation and changes will come with us :)"*

Discussion

Initial degree of food neophobia

The fact that no important correlation has been observed relating to participants' gender and their degree of neophobia is consistent with the study of Meiselman et al. (1998), who found that gender differences weren't noticeable when comparing young people's eating behaviors. Although no study has been found in the literature aiming to assess the degree of food neophobia experienced by young Canadians, a survey involving California university-level students (n=554) identified an average FNS score of 29.8/70 (Olabi et al., 2009). Another survey, this time involving Australian students divided into two separate high-schools – one situated in an urban area and the other located more remotely – revealed a FNS score ranging from 29.32/70 for urban participants (n = 696) to 34,68 for rural ones (n=243) (Flight et al., 2003).

The FNS results collected in the present survey (equivalent to 32/70) appear quite coherent with these observations. The vast majority (72%) of participating students were born in Canada, and the school they attended is located in a suburban area, which surrounding environment is characterized by the presence of very few restaurants promoting international cuisines. A much higher proportion of these Canadian born students marked as highly neophobic (15.8%), as compared to students originating from other countries that are known to contain entomophageous communities (Afr 7%, Asia 4.2%, and LAC 0%). This observation supports the finding that cultural identity is likely to influence the degree of food neophobia one can experience (Flight et al, 2003). However, it is important to cautiously acknowledge that students' country of origin does not allow to draw a straight parallel with their actual cultural background or ethnicity.

Knowledge, acceptance, and behaviors towards insect farming and consumption

At the beginning of the project (surveys A), the vast majority (87%) of participants mentioned knowing about the practice of entomophagy (it should be taken with a grain of salt, as it is highly likely that some of them had already heard about the upcoming projects), but only a quarter were aware of how widespread it was. It is not surprising that most of them (79%) had never tasted insects before, as their young age might has contributed to limit the occurrence of such trial opportunities – a theory which is supported by the fact that 63% of those who had never tried eating insects before mentioned being willing to do so (Table 3). Of all the students partaking in the present project, 29% initially mentioned being totally closed to the idea of eating insects. Most of the participants ranking as highly neophobic were in this situation. It supports previous evidence that neophobia represents a strong predictor of consumers' (un)willingness to eat insects (Hartmann et al., 2015; Verbeke, 2015).

Moreover, male participants were more likely than female ones to have eaten insects already (27% vs 18%), and amongst these experienced participants, a higher proportion of males also indicated a willingness to engage once again with entomophagy (85% vs 73%). If a greater acceptance of males towards entomophagy had already been identified in the scientific literature amongst culturally diverse populations (e.g. Florença et al., 2021; Ruby et al., 2015; Tuccillo et al., 2020; Videbæk & Grunert, 2020), it is interesting to observe that the great majority of our participants who mentioned having already tasted insects before (both male and female) were satisfied enough by their experience to be willing to repeat it once again.

As for their main motivations to consume edible insects (in survey A), all the suggested factors with the exception of "to be noticed" were considered at least somewhat important by the majority of our surveyed respondents. Ecological and ethical concerns (e.g. practical reasons) were significantly more popular amongst female respondents, whereas males were more tempted than females by both curiosity and to be noticed by their peers (e.g. personal or social reasons). Beardsworth et al. (2002), after analyzing the results of a large UK study carried out in the mid-1990's, concluded that women generally tended to be significantly more "sensitive", "caring", and "aware" of ethical, ecological, nutritional, and body image issues when it came to eating – to the point where thew would be more inclined to trying novel food items. This latter observation contrasts more recent studies which underlined men's greater exploratory food sense (e.g. Sogari et al., 2019a; Wilkinson et al., 2018) – although such a gender asymmetry as pertaining to neophilia appears less obvious amongst teenagers (Rossbach et al., 2016). Other studies have also suggested a heightened concern by women for the environmental (e.g. Niva et al., 2014; Sanchez-Sabate & Sabaté, 2019) and animal welfare (e.g. Blanc et al., 2020; Doswett et al., 2018) impacts related to meat consumption, but their focus was on adult rather than adolescent subjects. Regarding motivations relating to health and personal challenge, the present study observed a similar importance granted by both genders. Finally, about half of our participants initially thought that it was a good idea to have an insect farm in class, mentioning that the upcoming project was triggering their curiosity rather than scaring them.

Evolution of acceptance and behaviors towards entomophagy

Most participants declared having tasted insects for the first time of their lives over the course of the project – either during insect tasting activities that were organized at the end of each project units or independently. Over three quarters of the most refractory students (i.e. who had initially no experience with entomophagy and didn't intend to engage with insect tasting, as mentioned in survey A) actually ended up tasting insects during these three-month periods (as indicated in survey B). Through workshops and teaching activities, students were informed of the wide-ranging impacts of conventional meat eating (i.e. in a critical food pedagogy perspective). Educational presentations and "bug banquets" were previously found to have only a subtle effect on altering Canadian students' attitudes towards entomophagy (Looy & Wood, 2006). Hence, to complement this approach, the present research project was accompanied with the implementation of an innovative type of "farm to school" program, in which students were introduced an alternative and rather intriguing avenue to farm animals destined for human consumption. The integrative praxis at the core of this project – increasing participating youngsters' motivational drivers while developing their sense of ability – is believed to be highly responsible for having generated such effective behavioral change.

The motivations explaining this change in participants' behaviors towards entomophagy are found to be largely attributed to health, ecological, and ethical concerns (that these factors had gained greater importance in survey B, as compared to the scores they were attributed in survey A). At the end of the project, participants who were open to entomophagy appeared much less driven than they initially were by individualistic motivations relating to "personal challenge" (males) and "to be noticed" (both genders). Besides decreasing participating students' reluctance towards edible insects and altering social norms prevailing amongst the classroom, the project thus seems to have successfully aroused their food awareness – having proven effective in communicating and facilitating the understanding of the wide-ranging benefits associated with entomophagy.

Although female participants were initially found to be more reluctant than males towards engaging in insect consumption, both genders ended up with similar experiences and intentions relating to entomophagy at the end of the project. Hence, it seems to have had a greater impact on female participants, namely in successfully overcoming their reluctant behaviors towards entomophagy. As compared to male participants, a larger proportion of them have decided to consume edible insects for the first time over the course of the project. Globally, the project was appreciated by most of the participating students, as a majority (64%) of them mentioned being interested to learn more in class about insects and their farming methods, while 13% even declared being open to the idea of raising insects themselves at home.

Beliefs regarding the future of entomophagy

Acknowledging edible insects' relative advantage and ensuring their compatibility with one's values, practices and habits are fundamental steps leading to their successful adoption as food innovations (Rogers, 2003). The present project seems to have allowed participants to overcome these initial steps, as demonstrated by the fact that, following its completion, the great majority of participants were convinced that insects might represent an advantageous nutritional choice over conventional meat. Most of them also declared believing that edible insects should be made more widely available, and that they should also be more commonly consumed. A majority of participating students were even confident enough to predict that the practice of entomophagy is going to gain extensive popularity in North America.

Unsurprisingly, an even greater proportion of participants believed more animals should be fed using insects. Of course, human psychological barriers represent the main obstacles to the widespread adoption of entomophagy, which is precisely the main reason why this project was launched. Obviously, animals don't share such barriers with humans. Hence, many studies have focused their attention on exploring the potential to integrate edible insects in animal diets. Although such a practice can indeed display great relative advantages as compared to the use of animal feed formulations based on unsustainable fish-based and/or integrating crops that could be used to directly feed humans, it just doesn't appear as efficient (e.g. in terms of calorie conversion ratio and food transportation) as directly integrating insects in human diets.

Preferences for insect-based products

Overall, participants initially declared having a much greater preference for powdered insects, followed respectively by crushed and whole ones. Low neophobic (LNp) participants were much more willing to consume visible insects (i.e. either whole or crushed) as compared to MNp, who themselves were much more willing to do so as compared to HNp. Powdered insects, at the opposite, were more popular amongst MNp and even more amongst HNp. A similar trend is also observable amongst genders: male participants were more willing to consume visible insects, whereas females were more willing to consume powdered insects. These observations are partly in line with a previous study describing potential Western consumers of insect-based foods as highly neophiliac (i.e. craving novelty) young males (Verbeke, 2015). However, the present study could only validate such characteristics as regards to insects in a visible form; not in the powdered one – which was unsurprisingly identified as the most preferred form for consuming insects amongst participating students.

Therefore, it appears possible that insects in the powdered form might not trigger asymmetric reluctant behaviors relating to consumers' gender or degree of food neophobia, as it appears to be the case (in this study and in many others) when it comes to eating insects in the whole form – or perhaps this observation is only valid for younger individuals. Hence, concealing edible insects' visual properties through processing might represent a successful avenue to bypass reluctant behaviors that are not only associated to their organoleptic features but also to the consumption of unfamiliar foods (i.e. neophobia) – thus leading to the enhanced possibility of marketing such products to an audience that expands beyond the highly adventurous eater. Once powdered, unknown foods like edible insects might be deemed more appropriate by consumers, namely as they can be more easily incorporated with familiar ingredients (Shelomi, 2015) and preparations (Tuorila et al., 1998) that can help imply edibleness and trigger positive sensory expectations –

thus enhancing the perceived suitability of such insect product preparations (Tan et al., 2017b). But as the present assessment of youngsters' willingness to taste insect products in based only on survey results rather than on actual tastings, it is a subject that would require further investigations.

Concerning taste associations within insect-based foods, both genders were not quite sure whether they would prefer eating insects associated with sweet or savoury recipes. Participants were initially slightly less likely to associate them to a sweet recipe, but this position seems to have shifted by the end of the project – and that it possibly after engaging in tasting activities where both sweet and savoury recipes were presented to them (e.g. whole seasoned, sweet bars, brownies, and pasta). Likewise, all three cohorts ended up with a preference for crickets, at least in the powdered form. As for whole insects, participants developed a preference for the type of insects that they had been familiarized with in class while engaging in farming activities (i.e. crickets or mealworms). This observation strengthens the hypothesis that exposure and familiarization can play a great role in promoting consumers' acceptance towards insect-based foods (Tan et al., 2015). However, all these preferences were not assessed by systematically tasting insect products, meaning that many participants have self-reported their answers based only on their beliefs at the time of completing the survey and/or on inferred organoleptic features.

Impact on peer influence

The third cohort partaking in this project (starting in October 2019) started it with both a greater experience with insect consumption and a less pronounced reluctance towards entomophagy, as compared to the two other participating student cohorts (starting in February and October 2018). Hence, within a single year, entomophagy seems to have been significantly normalized amongst students of the science and technology program. This observation demonstrates the rapid and significant impact that peer influence can play at a young age, especially when youngsters acquire valuable knowledge about issues that resonate with their personal values and for which they feel empowered. The fact that group-based actions were at the core of this project has likely contributed to its success in altering collective behaviours in the classroom, as students tend to widely adhere to social norms prevailing in their social circle. Besides significantly altering participants' perceptions and behaviors towards entomophagy, launching such a project in the school environment is likely to have also aroused the curiosity of the other students who were not directly involved in it, hence widening the scope of its impact. As youngsters also hold a great influence on their family and the goods being purchased in their households, further studies could attempt to measure the impact of such programs aiming to promote youngsters' acceptance towards entomophagy on the punctual or repeated consumption of insect-based foods at home.

Conclusion

The project hereby discussed reveals interesting insights that can be leveraged in order to improve the efficiency of future communication and marketing campaigns designed to promote the adoption of edible insect products. For instance, males and females are found to be driven by different motivations for eating edible insects, as well as having distinct preferences for such products. Consumers' degree of neophobia (or neophilia) also seems to have an impact on their preference for specific edible insect forms (whole, crushed, or powdered). Hence, commercialization efforts should take into account such disparities amongst potential insect consumers – perhaps by diversifying their product line, with different products being targeted at specific audiences, perhaps each relying on tailored marketing tactics.

Over the course of these three-month projects, edible insect consumption became significantly normalized amongst participants. Enhanced exposure and familiarization seem to have played a great role in promoting their acceptance towards insect-based foods. In the light of the findings of the present research, the speed and impact of youngsters' peer influence should be leveraged in promotional efforts aiming to accelerate the adoption of edible insects amongst Westerners. Integrating theoretical and applied components in school curricula through the implementation of educational and participative insect farms is likely to overcome food neophobia and encourage the development of children's food sense, thus promoting the adoption of early sustainable food habits. Generating discussions towards agri-food systematic issues – such as social and environmental sustainability, human health, and food security – is essential to the rise of citizen-consumers. Understanding the wide-reaching impacts of their everyday food decisions, citizen-consumers show a strong desire to trigger change amongst the food system. Their food awareness translates into greater respect towards traditional and culturally diverse culinary habits, as well as an enhanced appeal for natural, ethical, and local products (Morin, 2017).

The main limitation of this study is that participating students were all enrolled in a science and technology program. Hence, their heightened interest for environmental issues in link with the present project might not be representative of the average adolescent. This project addressed Lewin's (1943) two initial phases of group dynamics aiming to achieve individual change, namely the reflection leading to the abandonment of initial behaviors and the experimentation with new practices. However, it doesn't allow us to verify whether or not the third phase was actually reached: the integration of new habits. Further studies should focus on attempting to validate whether or not such an impact is observable amongst participants (i.e. if they indeed engage in insect eating on a regular basis) and, if not, on identifying further avenues likely to lead to the successful normalization of edible insect consumption amongst youngsters – whose characteristics regarding food choices underline their potential to become lead users of such sustainable discontinuous food innovations.

Foreword to Chapter 5

In the previous chapters, we have focused our attention on assessing and alleviating consumers' main psychological barriers preventing the popularization of entomophagy. Although we have seen that edible insects' price and availability don't appear as important factors preventing insect trial, they definitely represent crucial barriers that must be addressed in order to support the widespread adoption of insects as an everyday foodstuff.

This chapter thus focuses on industry-level practices that could alleviate production costs and thus provide potential consumers with more affordable products. It draws on my experience as an "entopreneur" and the solutions my colleagues and I came up with in order to ensure the viability of our enterprise in such a quickly evolving sector. Throughout the different sections of this chapter, I will address how following industrial ecology principles can allow for the implementation of both sustainable and profitable insect farming practices.

Wishing to positively influence future entrepreneurs in this sector, it provides the preliminary results of plant-growth experiments I led using insect frass as an organic fertilizer. Moreover, it attempts to estimate the potential productivity of a medium-scale insect farm, as well as the required inputs as insect feed it might require. It also tries to quantify the economic benefits of relying on organic waste as insect feed, of selling insect frass as a farming by-product, and of developing industrial symbiosis – including sharing economy networks – with a wide range of potential partnering industries. It is intended for publication in the *Journal of Insects as Food and Feed*.

Chapter 5: How following industrial ecology principles can enhance the profitability of insect farms: my experience as an "entopreneur"

> *"When farms change into large industrial units it is going to create a demand for a number of experts who are not now available – agricultural engineers for want of a better name. They must be considerably better grounded in biological and chemical science than is the average "cow college" graduate, (...) know something of personal problems, for they must handle men, (...) know economics and business principles, for they will engage in changing and uncertain business, (...) know entomology and the trials of insect pests, (...) know fungus diseases and what to do and when, (...) know fertilizer chemistry and soil physics, (...) study markets and commercial trends, (...) be enough of mechanical engineers (...). I do not know where there are many such men, but they will be needed."*
>
> C. Furnas, 1936 (p. 304)

Introduction

In the past decade, edible insects have been subjected to massive scientific interest and media coverage, in the quest for sustainable human diets that allow for growing world populations to thrive. Insect farms have quickly proliferated throughout the world, as many entrepreneurs sensed what seemed like a potentially lucrative business opportunity. In the second half of the 2010 decade, demand for edible insects kept on rising, whereas bulk sale prices remained quite high (roughly CAD$ 100 / kg for crickets and mealworms, the two main commercialized insects for human consumption). Of course, psychological barriers are widely acknowledged as important obstacles preventing the widespread popularization of entomophagy (i.e. edible insect consumption). Marketing tactics to overcome such reluctance are already being studied by many consumer behavior scientists from across the world. If strong mental blocks are clearly preventing consumers' willingness to try edible insect products, their excessive prices on local markets represent an important barrier to their regular consumption. Such high costs also represent a major obstacle to their use as animal feed – a sector which is rapidly gaining significant interest in the quest of developing sustainable and healthy diets for poultry, livestock, fish, and domestic pets (Gasco et al., 2018; Sogari et al., 2019b).

The edible insect market for human consumption in North America was valued at US$ 55 million in 2017 and was expected to grow by 43.5% by 2024, as its worldwide market was predicted to attain US$ 520 million in 2023 (Ahuja & Deb, 2018). But the sector ended up growing even faster than expected. Its recent reassessment this time predicted a yearly 47% growth up until 2026 – jumping from US$ 112 million to US$ 1.5 billion (Ahuja & Mamtani, 2020). And these numbers don't even take into consideration the feed sector for farmed animals, which relies on the use of 30 million tons of cereals each year in Canada only (MAPAQ, 2020) – an industry valued at CAD$ 4 billion (ANAC, 2019). Moreover, the pet food industry generated an additional CAD$ 2.2 billion in sales in 2018 (Dangbedji, 2019). A such rapid growth in the edible insect industry triggers critical questions regarding the security and sustainability of farming practices, especially those being adopted by large scale producers. Indeed, as stressed by Shine (2021), the edible insect farming sector is currently characterized by "*a tendency towards concentration in the hands of a few massive players rather than a constellation of smaller ones*".

Prima facie, raising insects doesn't seem to require much specific knowledge. Many homemade videos and step-by-step entomoculture (i.e. insect farming) guides can be easily found online. A plethora of active discussion groups also quickly provide answers to farmers' interrogations. But one must keep in mind that domesticated insects are animals separated from their natural habitats and, although they indeed have the impressive ability to survive in harsh settings, they thrive only under specific environmental and dietary conditions. Moreover, insect farms are highly vulnerable to many pathogens – including viruses, bacteria, fungi, protists, and nematodes (Eilenberg et al., 2015). Hence, raising insects in unsanitary environments and/or without following rigorous protocols that ensure reliable product traceability can induce serious threats to human health.

"Entopreneurs" often neglect the essential biological knowledge required in order to implement productive insect farms. As a result, small-scale insect farms are shutting down business almost as quickly as new ones emerge. Meanwhile, the few large-scale insect farms that have been in operation for a little while keep on consolidating their processes and increasing their market shares. As they expand and achieve significant productivity gains, insect prices on the market are dropping considerably (mealworms and crickets can now be bought in bulk under CAD$ 35-40/kg). But as it has been the case previously in other food production sectors, such a quick growth is often achieved at the expense of compromised sustainability. In order to remain lucrative, smaller farms must innovate by finding smart ways to optimize their farming operations, allowing them to reduce their fixed costs, and/or diversify their revenue streams.

Industrial ecology

Highly sustainable practice models developed by humans are often found to be deeply inspired by ecological processes that occur in natural ecosystems (Abson et al., 2014; Whiteman et al., 2013). Biomimetic is the attempt to emulate natural models, systems, and elements for the purpose of solving complex human problems (Vincent et al., 2006). Applied to industrial processes, it represents what is called the "industrial ecology paradigm" (Ehrenfeld, 1997). Nature is governed by an intricate set of dynamics and rules, all of which support ecosystems' homeostasis – a process providing stable enough environmental conditions to allow life and biodiversity to thrive on earth. This characteristic is responsible for enhancing ecosystems' resilience, thereby ensuring their ability to recover from major catastrophic events. Acknowledging and adhering to basic natural principles within anthropogenic environments can allow for the achievement of sustainable innovations in a variety of human-led projects.

In nature, symbiosis dynamics allow for two or more living organisms to mutually benefit from close associations between one another, a relationship which is termed "mutualism". Developing similar relationships in the industrial sector can lead to the optimization of both material and energy consumption (Frosch & Gallopoulos, 1989). Industrial ecology relies on the collaboration of two or more organizations with a strong desire to innovate – often operating in more or less distinct sectors (Walter & Scholz, 2006). Such a partnership can help leverage human efforts in terms of thinking, developing, implementing, and maintaining sustainable and cost-effective processes. By attempting to replicate natural dynamics in human-built industrial ecosystems, we can develop resilient businesses that are able to overcome sanitary, economic, and ecological crises regularly affecting worldwide societies – which unfortunately aren't expected to settle in the near future.

Circular economy

Circular economy is a way to achieve industrial symbiosis. It can enable two or more partnering organizations to benefit from lower money and energy expenditures associated with both resource acquisition and waste disposal. According to a recent report, 58% of food is wasted in Canada, a majority of which (79%) occurring at the consumers' upstream (i.e. during harvest, transport, handling, processing, storage, or retailing) (Gooch et al., 2019). Organic waste management is one of the main contemporary challenges that must be addressed in order to fight climate change and ecological degradation. Following industrial ecology principles, taking a closer look at how food systems operate within natural ecosystems is likely to provide insights on ways to achieve circular waste management practices (Geng et al., 2009).

In nature, trash doesn't exist, as organic wastes are being constantly being recycled. One specie's food leftovers, its remains, and even its feces, all constitute a resource for another. Detritivores (i.e. protozoa, bacteria, fungi, and insects) are ecosystems' decomposers. Their role is to break apart decaying organic matter in order to make nutrients available for primary producers. Insects are especially important, not only as they dig tunnels in the ground to support the role of other decomposing microorganisms, but also as they represent in themselves a source of protein for species higher up in the food chain.

In human societies, organic wastes (i.e. whether industrial or domestic) typically all follow the same path. Most go to landfills and incinerators; others are used to produce biogas and compost – still with the help of reliable decomposing organisms. Insects participating in human-built composting facilities have a specific role: they eat the nutrients that compose food wastes and efficiently transform them into body mass. However, as opposed to their responsibility in natural ecosystems, detritivorous insects are not being used to then feed other species in the food chain. The natural life cycle is thus aborted. The only goal of insects in composting facilities being to degrade food nutrients, anthropogenic organic waste cycles are thus "downcycling" (rather than upcycling) foods. To improve waste management systems' functionality, it is critical to foster upcycling processes by which the outputs of one sector can serve as inputs for another.

Upcycling organic waste as animal feeds

After source reduction and supplying food banks, the American Environmental Protection Agency (EPA) believes that the optimal recycling method for food waste is to convert them into animal feed, a process which should be prioritized over biofuel production and composting (USEPA, 2016). This is not a new trend, as small swine operations surrounding cities have been using urban food waste as animal feed for centuries. The European Union (EU) regulations are also pointing in that direction – although they haven't yet fully legalized the use of food waste as animal feed due to disease control concerns (Salemdeeb et al., 2017). In 2016, only 3% of food wasted in EU was being upcycled by relying on such methods, whereas in Japan and South Korea – where heat treatment, storage, and transportation processes of food waste are strictly legislated – this proportion has already reached 40% (Sugiura et al., 2009; Zu Ermgassen et al., 2016). Circular waste management practices involving animals lead to fewer environmental and health impacts as compared to composting and biogas production (Salemdeeb et al., 2017). Additionally, it can considerably enhance the environmental sustainability of animal farms, while also reducing their spending in feed acquisition.

Due to restricted urban space and the undesirable odors related to manure management, pigs nowadays are farmed further away from cities. Bringing urban food waste all the way to pig farms would thus involve long distance transportation. Coming back to the natural food cycle, emphasizing the role of insects in human organic waste management practices might help depict a truly circular practice model. Bioconversion through insects can allow for the reintroduction of food waste in the food chain, while generating sustainable proteins that can be used in both human and animal diets (Hénault-Ethier et al., 2017). Through their omnivorous diet, insects can help us sustainably management these wastes at the very local scale (Cabrera et al., 2015). A recent survey conducted by Marquis et al., (Chapter 3 of the present thesis) reveals that Canadians strongly support the idea of feeding edible insects with organic waste. Moreover, another survey aiming to better assess Canadians' knowledge, perceptions, and behaviors towards entomophagy revealed that environmental concerns appear as a top motivation amongst those who would be willing to eat insects (Hénault-Ethier et al., 2020). Further enhancing the ecological benefits related to insect consumption might provide an additional incentive to turn potential entomophagists into actual bug eaters. As for insect farmers, integrating such circular processes can allow them to significantly lower their expenses related to feed acquisition.

As circular economy revolves around closed loop resource integration, insect farmers should also attempt to upcycle their own farming by-products. Insect frass (i.e. their excreta and shed skins) can act as a fertilizer in a similar way to compost, as they are both rich in trace elements and organic matter – which contributes to improving soil life, its structure, and its resistance to drought, while achieving carbon sequestration (Bot & Benites, 2005). Frass-amended soils are characterized by increased microbial metabolic activity and diversity (Houben et al., 2020). They can also help plants resist stresses such as drought, floods and salinity (Poveda et al., 2019). As it is rich in chitin (originating from insect shed skins), insect frass also has phytosanitary properties (i.e. antifungal and insect repellent) (Kombrink et al., 2011). In addition to accelerating plant growth, frass it thus believed to provide protection against invasive insect attacks as well as fungal diseases. Chitin is also of great interest for many industries, such as pharmaceuticals, biotechs, as well as textile and cosmetic producers (Morin-Crini et al., 2019). Hence, insect farms hold the potential to create truly circular agri-food systems, which can generate a diverse set of value-added surplus products (Bhatt et al., 2018). It can allow for insect farmers to maximize and diversify their revenue streams, while increasing the sustainability of their business model.

Upcycling materials

Sharing knowledge and materials amongst their users represents another way to follow circular economy principles – a process commonly referred to as "sharing economy" (Heinrichs, 2013). In the 1990s, eco-industrial parks emerged with the goal of creating bounded systems allowing for participating organizations to achieve savings related to resources sharing, thus fostering economic cooperation while generating benefits at the environmental and community levels (Chertow & Park, 2016). Obviously, the key rationale triggering private actors' interest towards such collaborative practices resides in their potential to achieve considerable cost-related savings. Indeed, sharing economy can enhance operational performance while generating direct economic benefits, thus leading to the acquisition of critical competitive advantages (Park & Park, 2014).

Sharing resources can allow for insect farmers to optimize their processes, thus substantially reducing their operating costs. Substantial business starting costs are related to the need for insect farmers to acquire essential materials and infrastructures. They represent the first economic obstacle faced by most start-ups interested in launching a business in the food production sector. Moreover, fixed costs represent another burden for these organizations, as they tend to remain quite stable over time: on a recurring basis, insect farmers must pay rent, salaries, insurance, as well as energy, web hosting, and other utility bills. They can lead to bankruptcy in periods when businesses are hit by unexpected issues that can severely affect their production operations and/or sales – as it has largely been the case following the recent COVID-19 outbreak.

Building partnerships between organizations in order for them to share common physical and/or human resources can help enhancing their economic resilience, thus allowing them to cope more easily with unanticipated disruptive events. Through such mutually beneficial relationships, organizations can collaborate in order to achieve economies of scale and share the burden of both starting and fixed costs – namely those that are related to the acquisition, maintenance, and use of space, materials, specialized equipment, infrastructures and even labor. Obviously, the implementation of sharing economy practices is often largely facilitated by the physical proximity of the organizations involved (Ristola & Mirata, 2007). As agricultural cooperatives are most often form with the aim of achieving such assets sharing amongst members, they form an ideal setting for farmers to optimize their investment while limiting its associated risks (Asian et al., 2019).

In the following pages, I will address important challenges I have personally come to face as an "entopreneur" launching an urban mealworm farm[14]. I will suggest avenues based on industrial ecology principles that can lead to successfully overcome such issues – from circular production processes involving organic waste upcycling to resources sharing with other organizations, both allowing the achievement of environmental, economic, and social benefits.

Methodology

This investigation links together research and action through a rigorous process of critical reflection. Action research is an empirical process of problem-based investigation by which practitioners aim for the creation and sharing of knowledge leading to achieve transformative change. As it combines theory and practice, action research is often facilitated by the participation of an existing organization. In this case, I will reflect on my own experience as co-founder of both an insect farming company and an urban agriculture cooperative.

According to Susman (1989), five phases are involved in the action research cycle: (1) identifying a problem and collecting data for a more detailed diagnosis; (2) postulating several possible solutions and identifying an action plan; (3) collecting, analyzing, and interpreting data on the results of the intervention; (4) evaluating how successful the action has been; and (5) reassessing the problem and potentially initiating another cycle. For the present paper, I first identified four economic problems insect farming organizations are likely to face, based on my experience: (a) heavy starting costs linked to the acquisition of essential farming materials; (b) considerable fixed costs in purchasing insect feed; (c) expensive resources and infrastructures needed for the processing, storage, and distribution of marketable products; and (d) economic vulnerability due to undiversified revenue streams. In the following sections, I will expose solutions to these problems inspired by industrial ecology principles. I will then attempt to assess the economic benefits that could be generated by these solutions, as well as the underlying challenges that their implementation might raise.

[14] Our mealworm farm was launched as an academic spin-off enterprise – allowing us to independently carry insect feeding and plant growth experiments (using insect droppings) in our own facilities. Roughly one year after its creation, I left the company in order to focus on my academic path.

Due to the important challenges already raised by the commercialization of edible insects and frass – two products which average consumers are unfamiliar with, thus requiring tremendous marketing efforts – potential sales revenues will be estimated based on bulk prices. Following my personal experience, I highly recommend that insect farmers first focus on optimizing the many processes involved in insect farming rather than attempting to expand their activities to the whole consumer supply chain. Packaging and retailing require specific knowledge and intensive efforts that can drain a lot of time and energy. Although retail sales can indeed potentially multiply revenues (as products can be sold at a higher price), they also imply a bunch of tasks that are either highly underestimated or bluntly unforeseen. Hence, my advice is to rely on other companies specialized in these activities, at least for the few years – that is until insect and frass production processes (e.g. farming, sifting, processing) have been perfected.

Feasibility of upcycling organic by-products as insect feed
In order to assess the feasibility of feeding insects using organic by-products, I undertook in 2018 an internship at the *Montreal Biodome* – part of the largest natural science museum complex in Canada. Mealworms were fed using wastes (i.e. spent mycelium) originating from a neighboring mushroom farm – itself growing grey-oyster mushrooms on a substrate composed of by-products salvaged from nearby coffee shops and breweries. Our hypothesis was that SMS (spent mycelium substrate) could partially replace the staple diet of mealworms (i.e. wheat bran).

First, we had to confirm the benefits of using SMS as compared to pre-inoculated substrate (i.e. before it is used to grow mushrooms). In order to do so, we divided a hundred glass worms (i.e. about 2 mm mealworm larvae) in ten 500 ml containers (two treatments, five replicates): five of them contained 16 grams of pre-inoculated mycelium substrate (equivalent dry weight, or EDW), and five others 16 grams of SMS (EDW). Both treatments were supplemented with four grams of wheat bran. Lids were perforated to allow air circulation and containers were placed in incubators which temperature was set at 27°C, with a relative humidity maintained at 40%. Each week and for a 12-week period, five larvae were individually weighed in each container, after which two grams of water were sprayed in every container. Our results confirmed that larval growth was significantly greater in the mycelium-enriched substrate, thus validating our hypothesis that SMS could represent an interesting feed source for mealworms (Hénault-Ethier et al., 2018).

Then, we undertook an experiment aiming to identify what percentage of SMS introduced in mealworms' diets would allow to generate greater larval growth. Treatments were composed of the control diet (100% wheat bran) and four other diets where wheat bran was being partially or completely replaced by SMS (20, 40, 60, and 100%; Figure 15). As it was the case in the previous experiment, each treatment was replicated five times, in same container sizes, using the same larval density, and kept under the same environmental conditions. Finally, another experiment was carried in which we attempted to increase mealworm densities (i.e. 150 larvae in 7.5-liter containers) in order to assess if such dietary substitutions would be likely to prove achievable in an industrial setting. For this experiment, SMS has been dehydrated and pulverized (≤2 mm) before it was fed to mealworms. Treatments were composed of 100% wheat bran (control), 40% SMS, 80% SMS, and 100% SMS. Room temperature was kept at 23°C and cups with 100ml of water were placed in each rearing container (filled bi-weekly). Larval growth (ten individuals per container) was measured bi-weekly over a 12-week period. Laboratory analyses were also performed in order to compare the chemical and nutritional composition of both larvae and frass. These results will be discussed in the following section.

Figure 15. Treatments partly or completely substituting wheat bran (0%) with SMS (100%)

Aiming to gather fieldwork experience that could nourish my research in the field of insect farming, I decided later that year to co-launch an urban mealworm farm whose processes would be oriented towards achieving circular economy. This academic spin-off enterprise was housed in an urban agriculture solidarity cooperative, which was being launched simultaneously. The coop had the mission of providing affordable commercial space and shared infrastructures for urban food producers, processors, and distributors. Other founding members as well as those who were quickly integrated in the coop included mushroom growers, fish farmers, coffee roasters, urban market organizers, and local food distributors. Part of our company's first challenge has been to attempt to better balance our waste-based mealworm diet using a broader diversity of organic by-products, all salvaged from our partners' waste streams (e.g. spent grains, juice pulps, cocoa sheds and yeasts).

Assessing the benefits of insect frass as an organic fertilizer

As we also wanted our insect farm to upcycle its own generated wastes, we carried out plant growth experiments in the summer of 2020, aiming to compare the fertilizing properties of insect frass with that of municipal compost and hen manure. Thirteen edible plant species (sunflowers, sweet corns, and cucumbers, carrots, beets, radishes, cherry tomatoes, basils, kales, chards, arugulas, nasturtiums, and zinnias) were planted in "long beds" (made out of geotextile, which is a permeable fabric), each measuring 24" x 16" x 16" (inches). The long beds were then aligned on the coop's rooftop (see Figure 16), situated in Montreal's industrial *District Central* area.

Figure 16. Long beds aligned on the rooftop where plant growth experiments were carried

For space-saving purposes, some species were paired, following the advice of agronomy experts (see Figure 17). All tree treatments – each of them being triplicated in order to perform statistical analyses – were amended with the equivalent of 10% of their volume in soil as municipal compost (N-P-K: 9-5-5). The control treatment (containing only soil and compost) was to be compared with one treatment containing added insect frass (N-P-K: 3-4-2; representing 0,5% of its soil volume), and another treatment containing added hen manure (N-P-K: 5-3-2; representing 0,3% of soil volume). The amount of frass to be incorporated in the soil was identified during pretests (carried out in an indoor growing tent), aiming to compare the growth of basil plants having been amended with 0,1%, 0,5% and 1% of frass. As for the percentage of hen manure, it was calculated by simply balancing the nitrogen input with that of insect frass, as suggested by the agronomists we consulted. Both of these last treatments were re-fertilized at mid-season, using the same volumes of insect frass and hen manure that have initially been incorporated.

Figure 17. Organization of treatments for the plant growth experiments, adding either (C)ompost only or compost amended with additional (F)rass or (H)en manure

<table>
<tr><td colspan="9">Cucumbers: 2 ppt*</td><td colspan="9">Carrots: 24 ppt
Beets: 12 ppt</td><td colspan="9">Radishes: 24 ppt
Sunflowers: 2 ppt</td><td colspan="8">Arugulas: 24 ppt</td></tr>
<tr><td>F</td><td>C</td><td>H</td><td>C</td><td>H</td><td>F</td><td>H</td><td>F</td><td>C</td><td>F</td><td>C</td><td>H</td><td>C</td><td>H</td><td>F</td><td>H</td><td>F</td><td>C</td><td>F</td><td>C</td><td>H</td><td>C</td><td>H</td><td>F</td><td>H</td><td>F</td><td>C</td><td>F</td><td>C</td><td>H</td><td>C</td><td>H</td><td>F</td><td>H</td><td>F</td></tr>
<tr><td colspan="9">Sweet corns: 6 ppt</td><td colspan="9">Tomatoes: 2 ppt
Basils: 2 ppt</td><td colspan="9">Kales: 2 ppt
Chards: 6 ppt</td><td colspan="8">Nasturtiums: 12 ppt
Zinnias: 8 ppt</td></tr>
<tr><td>F</td><td>C</td><td>H</td><td>C</td><td>H</td><td>F</td><td>H</td><td>F</td><td>C</td><td>F</td><td>C</td><td>H</td><td>C</td><td>H</td><td>F</td><td>H</td><td>F</td><td>C</td><td>F</td><td>C</td><td>H</td><td>C</td><td>H</td><td>F</td><td>H</td><td>F</td><td>C</td><td>F</td><td>C</td><td>H</td><td>C</td><td>H</td><td>F</td><td>H</td><td>F</td></tr>
</table>

*ppt: plants per treatment

Species were planted in densities that supported their optimal growth, similarly to how they would have been cultivated on a commercial farm (see Figure 17). An automatic irrigation system was installed and programmed to provide all plants with the same amount of water twice a day. Each week and for all their growth cycle (up to 13 weeks), plants' lengths, their stems' diameters, and the number fruits they produced were calculated. At the end of the growing season, all the fruits were harvested, counted, and weighed. Although complete results of these experiments will be discussed in a separate paper, partial results regarding average plant growth and yield for tomatoes, cucumbers, and sweet corn are presented in the following section in a way to facilitate the quick visual assessment of the benefits of using insect frass for average non-professional gardeners (i.e. for communication and marketing purposes rather than for the rigorous explanation of the scientific experiment's results).

Economic analysis

Using a combination of personal observations and data retrieved from entomology literature, we will estimate the potential capacity of a fictive farm with a 500-square-foot (ft^2) space dedicated to insect husbandry[15]. First, we will calculate the total volumes of insects and frass that such a mid-sized farm could produce on a yearly basis, as well as the amount of insect feed it would require. We will then attempt to assess and estimate the economic benefits of: (1) using upcycled organic waste as insect feed; (2) commercializing insect frass; and (3) reusing and recycling materials as essential farming infrastructures, namely rearing totes and a racking system to support them. Finally, we will discuss the advantages and complexities of partnering with other organizations in order to share the costs linked to the acquisition, operation, and maintenance of the equipment and infrastructures required for farming and processing activities.

Results and discussion

Insect feeding experiments

After six weeks, larval growth was found to be significantly greater in treatments containing 20% and 40% SMS. However, after ten weeks, larval growth was similar in 100% wheat bran, 20% SMS, and 40% SMS – although treatments containing SMS were characterized by a greater proportion of larvae having reached pupation. Treatments containing a larger proportion of SMS (i.e. 60% and 100%) showed slower larval growth after six and ten weeks. This first experiment thus suggests that it is possible to replace up to 40% of wheat bran with SMS in order to use upcycled mushroom production by-products as insect feed. Results were gathered in a poster format (Marquis et al., 2017; see Appendix N) and have been presented as part of an international entomology congress (Hénault-Ethier et al., 2018).

In the experiment that was carried on a larger scale, it was found that the high moisture content (57%) of SMS is likely an important contributing factor to its capacity to enhance larval growth. Laboratory analyses (see Appendix O) also revealed that SMS substitution increased the Ca:P (serum calcium to phosphorous) ratio of mealworm larvae. Additionally, it also contributed to boost the fertilizing values of mealworm frass (i.e. its content in N_{tot}, P_2O_5, K_2O, Mg, Mn, and Fe) and to increase its stability (carbon to nitrogen ratio, or C/N). Therefore, our experiments revealed that, not only could mealworms efficiently upcycle SMS, but using SMS in mealworm diets could improve the larvae's nutritional profile while also enhancing the fertilizing properties of their feces.

Along with attempting to upcycle a wider variety of organic by-products in mealworm feeds (e.g. brewers' spent grains, coffee grounds, juice pulps) (Varelas, 2019), future research should also attempt to assess the impact of these varying diets not only on mealworms' growth rates and nutritional composition (Oonincx et al., 2015; van Broekhoven et al., 2015; Zhang et al., 2019), but also on their palatability – which would ideally involve consumers partaking in product tastings that would compare whole, dried and unflavored insects having been fed either on a conventional

[15] In order to ensure the protection of confidential business information, the actual production numbers of the farm I co-launched will not be disclosed.

cereal-based diet or by relying on various types of organic wastes (each of these assessed separately).

Plant growth experiments

Overall, insect frass was found to have a similar impact as hen manure on promoting plant growth for cherry tomatoes, cucumbers, and sweet corns, as well as on the total weight of fruits each of these plants produced. Plants grown on both of these treatments were found to be much more productive than those growing in the control treatment (i.e. having been amended only with municipal compost). As for the other plants species that were subjected to the experiment, results will be discussed in a separate article. Nonetheless, the preliminary data hereby analyzed allow us to draw clear scientific conclusions on the benefits of using insect frass as an organic fertilizer.

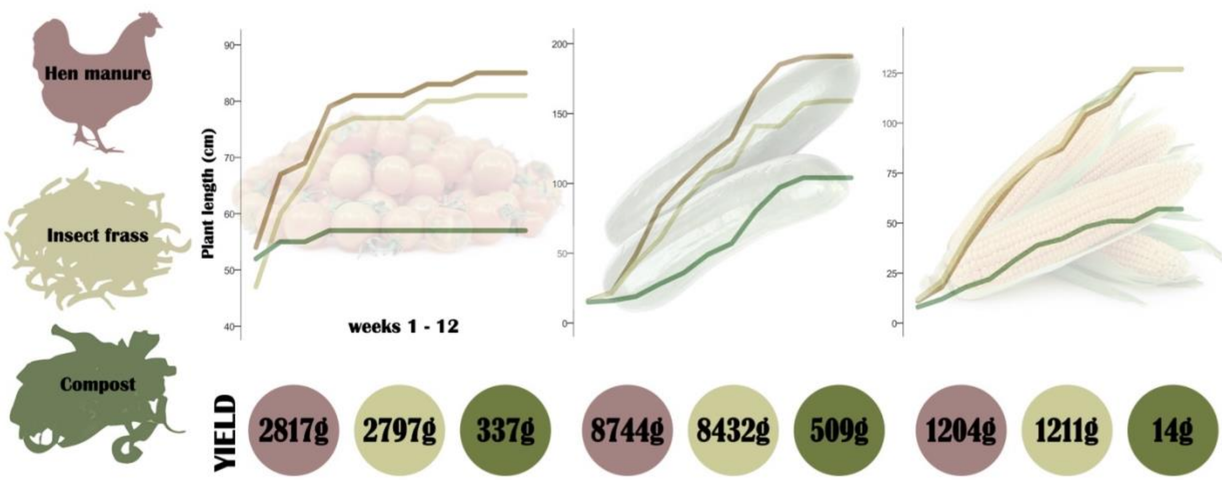
After ten weeks of growth, frass-amended cherry tomatoes (+42%), cucumbers (+51%), and sweet corns (+149%) had reached significantly higher plant lengths as compared to those growing in the control treatment, while also producing much higher fruit yields (respectively +830%, +1657%, and +8650%) (Table 23). Obviously, the nutrients available in the compost only treatment were largely insufficient to meet plants needs so that they could produce harvestable sized fruits, whereas insect frass has provided these nutrients with an efficiency comparable to that of hen manure – a commonly used organic fertilizer in agriculture.

Table 23. Plant growth and total fruit yield calculated in experimental treatments amended with compost only (C), compost added with hen manure (CHM) or compost added with insect frass (CIF) on cherry tomatoes, cucumbers, and sweet corns

	Cherry tomatoes (cm)			**Cucumbers (cm)**			**Sweet corns (cm)**		
	CIF	*CHM*	*C*	*CIF*	*CHM*	*C*	*CIF*	*CHM*	*C*
Week 1	47	54	52	15	16	15	12	11	8
2	60	67	55	22	22	16	21	18	12
3	66	69	55	43	49	19	42	38	18
4	75	79	57	60	84	28	60	55	22
5	77	81	57	87	103	36	72	70	31
6	77	81	57	106	119	49	82	82	39
7	77	81	57	113	132	57	89	87	42
8	80	83	57	141	166	80	108	104	48
9	80	83	57	141	185	97	113	110	51
10	81	85	57	157	190	104	127	125	51
11	81	85	57	159	191	104	127	127	57
12	81	85	57	159	191	104	127	127	57
Yield:	2797	2817	337	8432	8744	509	1211	1204	14

In order to facilitate the assessment of these fertilizing benefits for non-professional plant growers, results are illustrated below in a simplified format (Figure 18, original charts can be found in Appendix P). It allows us to observe that the most important productivity gains attributed to the use of insect frass were observed on sweet corns. As this experiment didn't aim to assess the many benefits that can be attributed to the chitin contained in insect frass (i.e. on enhancing plant health and protecting them from insect and fungi attacks), these remain to be assessed by a thorough research that would adopt a phytosanitary perspective. The impact of insect frass on the nutritional composition of the fruits produced is also another aspect that will need to be studied through an in-depth agronomic investigation.

Figure 18. Effect on plant growth and total fruit yield of adding compost only or compost amended with additional hen manure or insect frass on cherry tomatoes, cucumbers, and sweet corns



Space optimization
In insect farms, mealworms are typically reared in plastic bins, which sizes may vary widely according to farmers' preferences and constraints. However, as these bins must be acquired in very large numbers (depending on the size of the farm), farmers often make their choice based on price rather than ideal size and product material. Polyvalent utility totes are being widely used amongst mealworm start-ups in North America, as they are quite resistant and affordable (about CAD$ 5 each), widely available (e.g. often used in industrial kitchens), and their sizes are suitable for human handling (20" x 15" x 5"; Figure 19).

Figure 19. Utility tote commonly used by mealworm farmers in North America (left) and stackable tote (right)

source: www.tzanet.com (left) and www.beekenkamp.nl (right)

In a 500 ft^2 husbandry area, a way to optimize the use of the available space in order to house a large number of rearing totes is to divide the room into aisles using racking systems (Figure 20). Although some large-scale mealworm farmers choose to rely on stackable totes that don't require any racking (Figure 19), such a practice is rather inappropriate for unautomated and/or smaller facilities, as it requires to sacrifice additional rearing space for the creation of wider circulation aisles (for moving columns of stacked totes) while making it almost impossible to handle individual totes (e.g. when manually distributing feed on a regular basis). Hence, racking systems appear more suitable for our 500 ft^2 farm.

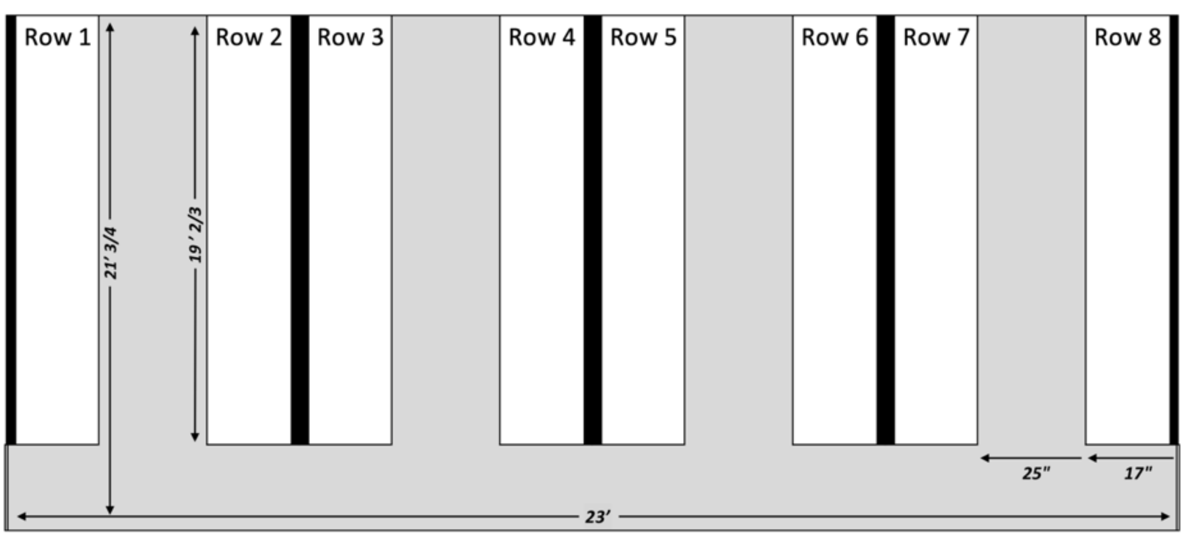
Figure 20. Typical racking systems than can be used to stack insect rearing totes

source: freavon.com

Rackings can be used to divide the husbandry into four aisles, each with accessible totes on both sides, for a total of eight racking rows (see Figure 21). Each of these eight rows can contain shelving on ten levels, thus allowing for arm's length manipulations (75"), while preserving floor clearance (5") to facilitate cleaning operations, and vertical spacing between each tote (1") to facilitate air circulation:

> 10 shelves x [5" (tote height) + 1" (airflow) + 1" (shelf thickness)] + 5" (floor clearance) = 75" (or 6'3") total height

Figure 21. Proposed space division in a 500 ft2 mealworm husbandry



Room dimensions can now be defined, starting by calculating the total width required in the husbandry to fit our eight racking rows. Shelves, supported by a freestanding racking structure (2”), must cover the whole length of the rearing totes (20”), while the aisles must be wide enough to allow trolley circulation (25”):

8 rows x [20” (tote length) + 2” (racking structure)] + 4 aisles x 25” (width) = 276” (or 23’) total room width

In order to calculate the number of totes that can fit in each row, we must first define the total distance on which each row can spread. It can be calculated by first dividing the total square footage of the husbandry area (500 ft^2) by its width, which has been calculated above (23’). Then, we must subtract an aisle’s width (25”), which must be sufficient to allow trolleys to circulate in and out of the room and from one aisle to another. Finally, we can count how many totes can fit in each row by dividing row lengths by tote widths (15”):

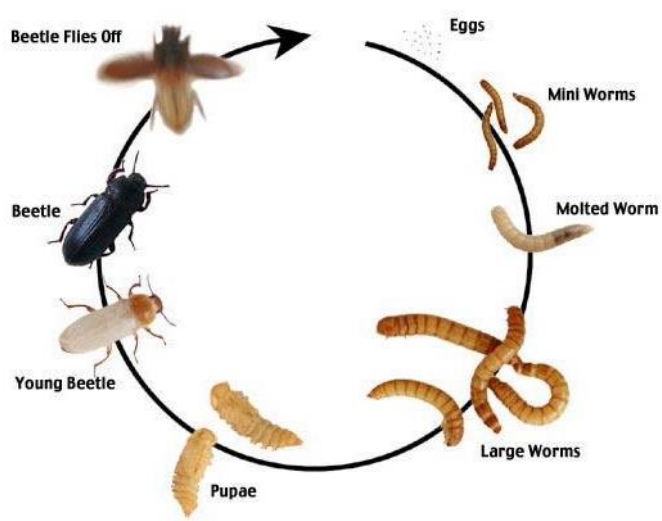
[500 ft^2 area / 23’ room width] = 21,74’ or 261” total room length
261” (room length) – 25” (corridor) = 236” total row lengths
236” (row length) / 15” (tote width) = 15 totes that can fit in each row

Hence, we now know that a total number of 1200 totes can theoretically fit in our 500 ft^2 mealworm husbandry space:

8 rows x 10 shelves x 15 totes = 1200 totes can be stored

Input and output estimates
Mealworms go through four life stages: from eggs to larvae, to pupae, and finally to adults (Figure 22). It is only at the adult stage (i.e. beetles, after hatching from pupae) that mealworms can lay eggs.

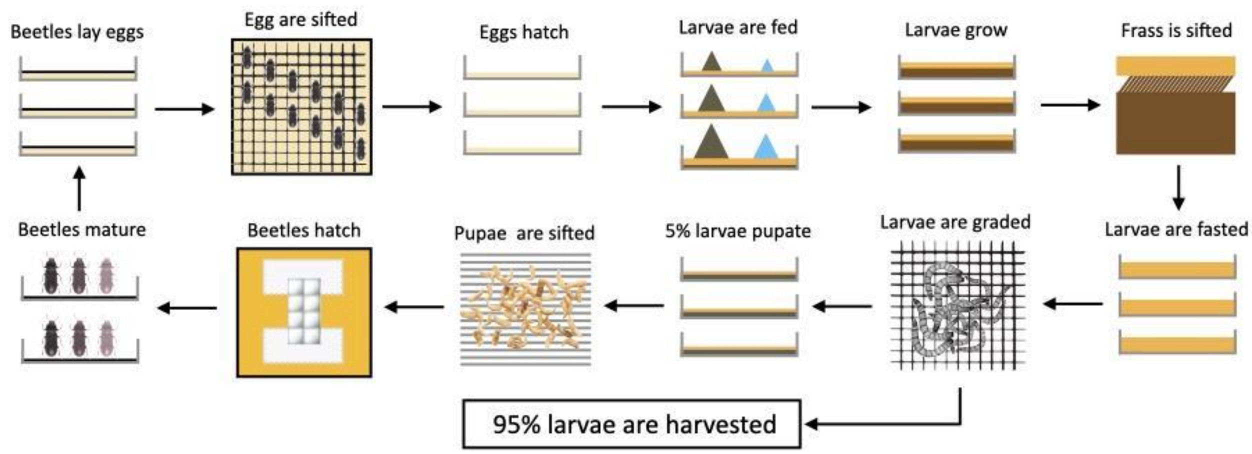
Figure 22. A mealworm’s life cycle



source: www.livinfarms.com

In order to compensate for larvae harvesting (i.e. the stage at which they can be used as human food or animal feed), our farm must ensure a constant production of mealworm eggs. Hence, a part of the husbandry must be transferred into the nursery (Figure 23).

Figure 23. The mealworm production cycle to ensure colony reproduction



For optimal reproductivity, breeding totes should contain 0.84 beetles per cm^2 (Berggreen et al., 2018). Due to the slight trapezoid shape of the rearing totes described earlier, their internal bottom surface was found to actually measure 18" x 12.5" (225 in^2 or 1450 cm^2). Therefore, each tote can house about 1200 beetles. As female beetles are highly productive – being able to lay up to 30 eggs per day (Drnevich et al., 2001) – a whole nursery (i.e composed of pupation, hatching, maturation, and breeding totes) can fit in one of the eight husbandry rows (see Appendix Q for precise calculations). Hence, the rest of the seven rows in the husbandry area can be used for larval growth, which totalizes 1050 totes.

In ideal conditions – with a room temperature maintained between 25 to 30°C (Manojlovie, 1988) and its relative humidity somewhere between 50 and 75% (Chen & Liu, 1992) – larvae take about ten weeks to reach a harvestable size (i.e. roughly 100 mg) (Erens et al., 2012). Five colonies of mealworms can thus be harvested in each of the 1050 totes used for larval growth in a single year. At harvest, each of these totes can be expected to produce about 1.5 kg of mealworm larvae (at densities reaching ten larvae/cm^2)[16], for a total annual production of 7875 kg. However, about 5% of these larvae must be transferred into the nursery to ensure constant mealworm reproduction (Halloran et al., 2018). Mealworms having an average water content of 62% (Nowak et al., 2016), our 500 $sq.^2$ farm could therefore be expected to generate 2843 kg of dried mealworms on a yearly basis – thus representing roughly CAD$ 114 000/year in bulk sales (at a CAD$ 40/kg market value):

> 1050 (larval growth totes) x 1.5 kg (yield) x 5 (colonies per year) x 95% (harvested larvae) x 38% (dry weight) = 2843 kg of dry larvae produced yearly
> 2843 kg x CAD$ 40/kg = 113 715 CAD$ per year in bulk sales

[16] www.bugburger.se/wp-content/uploads/2018/11/mealwormguide.pdf

Upcycling organic wastes

Mealworms' feed conversion ratio (FCR; i.e. the efficiency at which they can convert ingested food into body weight) can be used to estimate the annual weight of feed theoretically required for our 7875 kg of mealworms to thrive, as well as the amount of frass they can be expected to generate. Although important variations in mealworms' FCR are observed in the literature (especially when feeding them with a variety of organic by-products), a ratio of 3:1 can be expected when relying on a well-balanced waste-based diet (Coudro et al., 2019; Oonincx et al., 2015). Hence, our fictive farm would require roughly 23.6 tons of feed (equivalent dry weight) on a yearly basis, which by deduction (i.e. subtracting the feed converted by insects into dry body weight) would generate about 20.6 tons of frass:

7875 kg x 3:1 (FCR) - [7875 kg x 38% (dry weight)] = 20 633 kg of frass produced yearly

As insect frass represents a valuable by-product, it can allow farmers to generate additional revenues. Its bulk prices reach USD$ 2000/ton (CAD$ 2600)[17] – which is pricier than black soldier fly frass (CAD$ 1000-1500/ton)[18]. Therefore, frass could potentially generate CAD$ 53 646/year in additional revenues for our 500 ft^2 farm.

Although our calculations indicated that about 23.6 tons of feed would be needed on a yearly basis in order to fill the dietary needs of all the insects being housed in our 500 ft^2 farm, relying on salvaged organic by-products (e.g. SMS, fruits and vegetables pulp, brewers spent grain) would actually require much greater quantities of these raw materials in order to account for their high moisture. Considering an average 80% of water content in weight – as identified by Santos et al. (2003) for spent grain – a total of 118 tons of moist organic by-products would actually need to be collected in order to provide our insects with 23.6 tons of equivalent dry feed. As mealworms need to be provided with about twice their body weight in water over the course of their lifespan[19] (Coudro et al., 2019), part of these by-products wouldn't even need to be dried before being distributed in the rearing totes.

Food industries that generate such organic by-products usually need to disburse considerable waste management fees. Such fees are constantly increasing, as outdated landfilling practices are being gradually replaced by more sustainable (and expensive) methods. In the Montreal metropolitan area for instance, the true cost associated with the collection and management of organic wastes has been estimated at CAD$ 260 per ton (CMM, 2017). Although waste generators aren't yet asked to cover all of these costs, considerable increases in waste management fees are expected in the upcoming years (Lecomte, 2020). Whether by directly billing waste generators or by benefiting from potential public subsidies, upcycling organic wastes through entotechnologies (i.e. insect farming processes) represents an interesting opportunity for insect farmers to generate additional revenues while also securing their insect feed supply. Based on the above calculations, our 500 ft^2 farm could thereby offer waste management services valued at CAD$ 30 680/year.

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[17] www.kisorganics.com/products/natural-insect-fertilizer-frass

[18] www.divertns.ca/assets/files/Production-of-High-Value-Protein-Feeds-and-Fertilizer-from-Pre-Consumer-Vegetable-Waste-Utilizing-a-Novel-Black-Soldier-Fly-Larvae-Conversion-Process-%E2%80%93-Dr.-Beth-Mason-2016.pdf

[19] Our 7875 kg of mealworms would thus need 15.75 tons of water, which can be provided by 19.69 tons of organic by-products at 80% moisture – simultaneously providing the equivalent of 3.94 tons in equivalent dry feed (see Appendix Q for precise calculations)

Wheat bran is the most commonly used staple food in insect farms. In bulk, it can be purchased for CAD$ 500 per ton. By relying on organic by-products as insect feed, our fictive farm could thus achieve important savings. Indeed, it would cost no less than CAD$ 11 800/year to purchase the 23.6 tons of wheat bran required to feed its insects, as calculated above. However, it is critical to identify reliable partners on which you can count to provide you with by-products of homogenous quality on a steady basis. It appears also desirable to have backup suppliers, who will be able to take the lead and ensure the continuous provision of raw feed input when necessary – although keeping a stash of wheat bran is always a good idea in case of unexpected events.

Collecting, preserving, and drying organic by-products requires additional investments in terms of infrastructures and labor work. Organics' pre-treatment processes can also be quite demanding in terms of energy consumption, which should be considered when attempting to adequately assess the economic and ecological benefits of such circular farming practices. But as we will discuss in the following section, developing industrial symbioses can help minimizing such expenditures. It should also be acknowledged that pre-treatment processes involve quite a bit of trial and error before they can be optimized, so that organics' decomposition processes are considerably slowed down to efficiently control microbial activity, without significantly affecting its nutritional composition. On this aspect, a lot of research remains to be carried – although a growing number of insect farmers and scientists have been investigating the subject, thus paving the way to its related scientific literature (Chia et al., 2018; Isibika et al., 2019; Varelas, 2019).

Acquiring used materials and infrastructures

Upcycling organic waste and selling insect frass could thus potentially provide a total of CAD$ 96 126 /year in both additional revenues and feed cost savings for our 500 ft^2 fictive farm. This represents an 85% increase as compared to its total insect sales – which we have previously estimated at CAD$ 114 000/year. Although these numbers may seem quite appealing for aspiring "entopreneurs", implementing and operating an insect farm requires considerable initial investments as well as recurring costs.

We have seen earlier that farming mealworms involves the breeding and feeding of insects – both overly time-consuming steps. But before mealworm larvae and frass can be commercialized, additional actions must be performed, all requiring more facilities, equipment, and labor work. These essential steps namely include: (1) the collection, processing, and storage of insect feed; (2) the rearing of larvae in a humidity- and temperature-controlled environment; (3) the sifting of insects according to their different sizes and life stages; (4) the processing (i.e. freezing, boiling, and drying) of larvae; (5) the processing (i.e. sifting, freezing and drying) of insect frass; (6) the packaging and storage of dried insects and frass; (7) the delivery of marketed products; and (8) the cleaning of the space, rearing totes, and other materials used in each of the steps mentioned above. In the following paragraphs, I will discuss how industrial symbiosis can help insect farmers achieve important savings in terms of infrastructures, materials, and labor – which represent the main expenses of most insect farmers.

Rackings and insect rearing totes are amongst the first and most expensive investments to be made when launching an insect farm. As discussed earlier, utility totes (Figure 19) are probably the cheapest suitable option on the market. Still, at $CAD 5 per unit, the acquisition of the 1200 totes needed for our 500 ft^2 farm would totalize $CAD 6000 in expenses. Rackings require even greater investments: $CAD 6000 in gondola shelving units and $CAD 4000 in shelves to cover the specific needs of our fictive farm[20]. But as such rearing totes and racking systems are commonly used in a wide range of industries (e.g. transportation, warehouses, retailing, etc.), insect farmers can look for second-hand materials – potentially allowing them to save up to $CAD 16 000 in starting costs.

Although one must accept the unexpected failures he/she might face when walking off the beaten tracks, some might still appreciate being warned of a few common mistakes they might make. First, I have seen insect farmers crafting hand-made wooden structures instead of using proper racking systems. Using wooden materials in insect farms is highly likely to create mold problems and/or pest infestations, which can both be extremely hard to overcome and can have a detrimental effect on insect colonies. Second, when searching for reusable totes, I strongly advise closely inspecting their condition as well as paying a particular attention to their composing material.

At the time of launching our company, we were generously offered hundreds of plastic transportation boxes – which broken covers rendered useless for their previous owners. As we only needed the bottom part, we decided to cut each of them at a specific height to create our own customized rearing bins. Just a few weeks after transferring millions of tiny mealworms in their new homes, we realized that they were now conquering the entire farm. They were literally everywhere: on the floor, on the walls, on the curtains, in the sifting room… some had even managed to make their way into the coop's meeting room. Pictures of them crawling everywhere were posted in the coop's private *Facebook* chat, along with *emojis* of all kinds (not the smiley ones). It turned out the inside of the pre-owned boxes we had started using as mealworm rearing totes were covered with scratches, thus providing fantastic climbing walls for larvae. This was actually our second failed attempt to use salvaged rearing bins. We had previously tested seed starting trays, until we were quickly reminded of mealworms' incredible ability to digest polyethylene (Brandon et al., 2018).

Besides insect housing, many other materials and infrastructures are needed when farming insect and selling them on the market. In this section, we have only provided a glimpse of what can be achieved in terms of giving a new life – or finding a new use – to pre-owned physical resources. In the following one, we will explore how building partnerships with other organizations can help further limit the starting and recurring costs that should be anticipated when launching and operating a such enterprise.

Developing industrial symbioses

Finding the right organizations to collaborate with while avoiding the complications that can emerge when developing a close relationship with potential competitors can be challenging. A good starting point is to look at other actors evolving in parallel industries, who are likely to share a common vision, values, and beliefs (Walls & Paquin, 2015). For insect farmers, these could be other farmers who are tackling different markets (i.e. either raising different animals or perhaps even other insect species). It could also mean looking at other agri-food businesses that are involved in production, processing, packaging, or distribution activities – according to the specific symbioses one aims to achieve. Comparable to inter-company partnerships that are taking place in

[20] www.uline.ca/Product/Detail/H-3876/Gondola/Double-Sided-Gondola-Starter-Unit-48-x-35-x-72-Platinum

eco-industrial parks, joining an urban agriculture cooperative can be a great way to start developing such collaborations.

First, members of a cooperative can have access to a cheaper lease, as committing to rent a larger surface at once makes it easier to negotiate with commercial landlords. Additionally, important savings can be made by sharing infrastructures with others who also need them, such as offices and meeting rooms, storage spaces, commercial kitchens, refrigerated rooms, packaging stations, washing stations, toilets, and delivery vehicles. Not only do most of these infrastructures require to pay for additional square footage, they also involve expensive and most often underestimated costs related to material acquisitions and/or leasehold improvements, which most often can never be recovered. Such infrastructures are also costly in terms of cleaning, maintenance, insurance coverage, and energy consumption, whereas they will most likely be used only a fraction of the time.

Beyond sharing such materials and infrastructures with other users, partaking in efforts to share energy and human resources can lead to realize sustainable innovations, potentially allowing to achieve further savings. Physical proximity amongst complementary organizations can allow them to develop symbiotic processes (e.g. co-packaging, common distribution, organic waste upcycling loops) without having to rely on motorized transportation or the processing of perishable goods. Hence, a well-balanced insect diet can be formulated using various types of clean and traceable organic wastes generated on site. These insects can then be used *in-situ* to feed and improve the immune system of other farmed animals (e.g. fish or poultry), whereas their frass can be used in gardens or greenhouses to enhance the growth of fruits, vegetables and/or herbs. In order to provide thriving conditions for insects in the climate-controlled husbandry room, efforts can be deployed aiming to implement air recirculation systems using the heat and/or humidity generated by some types of machines (e.g. coffee roaster, food dehydrator, dishwasher[21]) – thus potentially realizing considerable savings on energy use.

Innovations thereby achieved can even lead to engage in a knowledge-sharing economy, thus providing the opportunity to generate additional revenues through consultation services offered to other organizations also aiming to optimize and improve the sustainability of their production processes. Partaking in efforts towards the development of industrial symbioses thus holds the potential for participating organizations to build social capital that might lead to strongly enhance their economic resilience. Hence, these organizations can more easily overcome unexpected situations that might affect their operations and temporarily compromise their ability to generate revenues – as observed amongst many insect farms following the recent COVID-19 outbreak.

Conclusion

The COVID-19 crisis has shed a light on the weakness of our globalized food supply chains. To cope with our societies' increasing pressure on ecosystems, it is important to review our conception of the urban landscape. Rather than bringing in foods produced outside of cities and exporting huge amounts of clean and traceable industrial organic waste, we must gradually attempt to reconceptualize resource flows amongst their borders. To transform the city into a functional ecosystem, it is critical to foster circular economy loops through which the outputs of one industry can serve as inputs for another.

[21] www.patents.google.com/patent/US6170166B1/en

Food production and transformation processes generate large amounts of traceable pre-consumer organic waste, a potentially highly valuable resource for insect producers. Circular edible insect farming methods can recycle these wasted foods while producing sustainable animal proteins within cities, therefore improving both food security and food sovereignty at the very local scale. Using edible insects to upcycle food waste is an interesting opportunity to add value to organic matter, as mealworm larvae and frass (estimated at CAD$ 42,600 per ton) have a much higher market value than compost (sold for less than CAD$ 100 per ton).

The present paper thus underlines the importance of reshaping food chains' geographical dynamics by gradually expanding the role played by urban areas beyond their current focus on processing, distribution, and, of course, consumption. Relocating more food production activities within cities would contribute to alleviating the pressure on transportation systems, while facilitating urban dwellers' access to fresh foods. Moreover, it would support the development of synergies amongst various actors of the food scene (i.e. from farmers to waste managers), thus helping design value chains that are leaning towards greater circularity of resources. Additionally, a greater physical proximity amongst food actors and research centers could be beneficial for food tech industries, potentially leading to the realization of systemic innovations within their processes, while fostering employment opportunities in many related sectors.

Inspired by naturally occurring processes, entomophagy and entotechnologies offer a holistic solution to alleviate the ecological impacts linked to the production and consumption of conventional livestock, while fighting food waste and reducing the carbon footprint associated with putrescible materials' poor management practices. However, edible insects' high market prices represent a major obstacle to their regular consumption, both as human food and as animal feed. The slow popularization of entomophagy is likely to trigger increased private investments allowing to achieve economies of scale through the automation of labor-intensive and time-consuming farming tasks, thus gradually lowering insect prices on the market. As a faster solution, upcycling organic waste, commercializing insect by-products, and developing industrial symbioses are all strategies that can allow insect farmers to lower their production costs while diversifying their revenue streams. These savings are likely to reflect on marketed edible insect products.

Considering the above discussions, political changes appear much needed in order to enhance the competitiveness of small- and medium-scale insect farms within the food market. Policies facilitating smaller and emerging players' access to investments would allow them to further optimize their operations, thus leading to the realization of productivity gains while saving on resource and energy expenditures – leading to enhance the sustainability of these enterprises. Redirecting government subsidies from mass production industries towards community-scale ones – especially those that are partnering together with the common goal of marketing fresh and sustainable foodstuff – would put tremendous pressure on larger corporations to revolution their practices. If building sustainable and resilient food systems is indeed at the top of governmental decision-makers' contemporary preoccupations, then it appears essential to implement food politics that support such inclusive supply chains and regenerative agricultural practices.

Chapter 6: Conclusion – Edible insects: a case for change in both consumers' minds and in the agri-food sector

Throughout this thesis, we have explored the many potential benefits of further integrating edible insects in human diets. We have also seen how entotechnologies can help fighting food waste and reducing the carbon footprint associated with the management of putrescible materials – although many industry-level challenges raised by insect mass production remain. At both the producer and consumer level, edible insects can thus be seen as an avenue to achieve systemic change in enhancing the sustainability of food supply and consumption practices. They can also promote greater food security, namely by enhancing food sovereignty at the very local scale.

In the introductory chapter of this thesis, I addressed four questions I wished to answer. First, which effective marketing strategies can help better support entomophagy? In Chapter 2, we have seen that – even though important psychological barriers are hampering edible insects' widespread adoption – behavioral science provides crucial insights on strategies and tools to help trigger radical shifts in consumers' food choices. Altogether, taking a closer look at the foodstuff's characteristics, in adequacy with consumers' traditional and evolving food preferences, and with the food environment at its different scales can help identify efficient marketing tactics leading to overcome perceptual barriers and to promote the adoption of edible insects in Western societies.

However, this chapter was written based only on a literature review and didn't attempt to qualitatively integrate consumers' point of view. Moreover, even a holistic approach – considering all aspects from processing to product labelling and positioning – cannot be expected to trigger radical and rapid changes in consumers' interest for edible insect products. Food habits are deeply rooted, and so are sociocultural constructs regarding insects. But although an even partial switch from macro- to micro-livestock is likely to spread on two or more generations, a better understanding of the processes leading to our Western aversion for edible insects can help develop strategies leading to its gradual decline. Our lowered reluctance might then support the perpetuation of entomophagy amongst traditional insect consuming countries and thus maintain its related culinary knowledge. This could, in turn, eventually lead to developing the next trendy insect-based recipe that will successfully spread throughout the world, perhaps replacing beef jerky at convenience stores' checkout…

As we highlighted the importance of a regionalized understanding of consumers' attitudes and perceptions, the second question I wanted to answer was: what are the behaviors and preferences of French Quebeckers towards insect products? In Chapter 3, we examined the results of a cross-cultural comparison with other Canadians in terms of knowledge, practice, motivations, and concerns towards entomophagy. We also analyzed French Quebeckers' singular preferences for such food products. Many studies have been and are still being carried in order to assess the position of various specific populations towards entomophagy. Although this approach appears indeed highly relevant to the better understanding of motivations and obstacles affecting the willingness to eat edible insects amongst various consumer groups, many of these studies ambitiously attempt to compare their results with that of other research that were previously led either in different countries or amongst distinctive socio-cultural groups. It is important to keep in mind that biases related to the use of different experimental methods can emerge when trying to draw such parallels.

As our study was performed applying the same protocol to both sub-populations being surveyed, it is believed to allow for the realisation of reliable comparisons. Yet, sociodemographic differences were still observed amongst these two surveyed groups, whose samples also cannot be considered representative of the general population. Similar flaws might also be responsible for hindering our attempts to assess the evolution of French Quebeckers' acceptance towards entomophagy, namely by comparing our respondents' responses to the same questions having been previously formulated in a 2016 survey – which was also geo-targeted to French Quebeckers but wasn't distributed through the same electronic channels. The recent development of a standardized questionnaire to assess respondents' attitude towards entomophagy (La Barbera et al., 2020) is a step towards the elaboration of homogenous research protocols that could allow for more reliable comparisons between different surveyed groups – though it appears insufficient by itself.

The third question I wanted to address was: can familiarizing youngsters with edible insects contribute to the popularization of entomophagy? As youngsters have been less exposed towards socio-cultural constructs and as their food habits are less entrenched, they might express a greater willingness to try edible insect products. Moreover, if marketing plays a huge role in nudging consumers towards specific products, our food selection is also largely subjected to influence by friends and relatives. As the rising social significance of dietary health and of sustainability issues are both contributing to enhance youngsters' food literacy, they are acquiring a better sense of the wide-ranging impacts of their everyday dietary choices. This can in turn lead them to engage in mindful decision-making, most often even becoming themselves agents of change for promoting a healthier and more sustainable diet.

In Chapter 4, I presented the results of a research project where high-school students were exposed and familiarized with edible insect farming and consumption. Over the course of these three-month project units, insect consumption became significantly normalized amongst participants. Hence, we concluded that the speed and impact of youngsters' peer influence should be leveraged in promotional efforts to accelerate the adoption of edible insects. However, it appears important to acknowledge that participating students were enrolled in a science and technology program, which could have increased their motivation for participating in the project. Moreover, as willingness to eat insect products was only assessed by relying on self-reported surveys, actual behavioral studies involving taste testing should be carried in order to validate our hypotheses. Further qualitative investigations, like tastings performed within focus groups, could allow for a more in-depth analysis of students' preferences – although sample sizes are likely to be much smaller, thus affecting the robustness of resulting statistical correlations.

Finally, the last question I aimed to answer was: how can we build sustainable and competitive insect farms? In Chapter 5, we explored how upcycling organic waste, commercializing insect by-products, and developing industrial symbioses (e.g. by reusing/recycling materials, or by sharing infrastructures, materials, energy, and knowledge with others) can allow for insect farmers to lower their operational costs while diversifying their revenue streams. The attempt of following such industrial ecology principles should guide current discussions aiming to organize and regulate the nascent insect farming industry. Besides promoting the accessibility of edible insect products by lowering their prices on the market, these practices allow for an efficient use of insects' full potential in contributing to achieve a transition towards sustainable food systems. It can lead to achieve sustainable innovations that might ultimately benefit to a wide range of industries.

In order to support such a transition in food production systems, it is essential to first understand and acknowledge our ecosystems' thresholds. Preserving natural habitats and biodiversity allows humans to benefit from invaluable ecosystem services, some of which aren't even yet fully understood. Food production systems should support rather than halt nature's ability to provide such services. Natural resources shouldn't only become valuable once marketed; their true value resides in their ability to maintain homeostasis amongst ecosystems. If nature conservation was given the importance it deserves, more efforts would be put into developing sustainable food production practices – those oriented towards fighting climate change, biodiversity loss, and food insecurity.

Demographic growth and dietary transitions are increasing the demand for protein-dense foods. But the meat production industry is already pushing natures' limits beyond capacity. Livestock farming is the main driver of deforestation. As forests are being gradually replaced by crop fields, soils are getting stuffed with excessive amounts of chemicals that leach into watercourses. As wild fish stocks are being overfished and as mangroves are being converted into large aquaculture ponds, biodiversity is being put at risk. It is this same biodiversity that enables ecosystems' adaptation to increasing environmental stresses caused by pollution and climate change. Destruction of natural habitats and biodiversity loss are hampering living beings' ability to overcome a wide array of stresses, diseases, and parasites, thus favouring the ease by which some viruses quickly spread throughout the world.

Facing increasing human dietary needs, there is an urgent need to improve agricultural production systems' efficiency, safety, and sustainability. Instead of putting nature at risk by increasingly relying on intensive agriculture, we must promote the adoption of regenerative supply practices while redirecting part of our focus on filling yield gaps towards overcoming considerable crop-to-mouth gaps in the agri-food system. This can be achieved by gradually eliminating food waste and by shifting towards the greater production and consumption alternative proteins. This way, we can optimize our use of natural resources and alleviate the pressure that is being put on food production systems. By ultimately halting land conversion, we will improve our ecosystems' ability to purify water and air, as well as to regenerate its soils.

Food production start-ups currently face unfair competition with multi-billion animal farming corporations that benefit from tremendous competitive advantages. By externalizing the indirect costs associated to meat production, its marketed prices are kept way below its true economic value. If environmental costs were being monetized and reflected accurately in foodstuff prices, greater incentives would be put towards the commercialization and consumption of sustainably sourced foods. Facing the true cost of food, consumers' food awareness would be leveraged, thus inducing shifts in their food habits that would eventually lead to achieve social changes in dietary patterns. Hence, beyond nudging consumers towards making mindful food choices, systemic issues relating to prevailing food production systems must imperatively be addressed (Carolan, 2017).

When consumers from all over the world will be provided with a wide range of affordable and palatable complete protein alternatives, and when meat prices will adequately reflect their true ecological cost, the switch is likely to occur rather quickly. Will insect burgers replace beef burgers in fast food chains? Perhaps not in the near future, but maybe one day – especially if younger generations are familiarized with entomophagy at an early age, and if tailored marketing tactics are adapted to geo-targeted populations as well as strategic consumer segments. Are insects the only solution to help fight climate change and world hunger? Definitely not. But the idea of eating insects is surely intriguing, and it can help raising consumers' awareness regarding the unsustainability of the current food industry at large. Meanwhile, innovations in insect farming, processing, and marketing practices can lead to achieve critical breakthroughs that could benefit to a wide range of sustainable and alternative food products.

Alternative proteins such as cellular meat, algae, jellyfish, and insects are all gaining increasing interest amongst the scientific community as well as private industries. Yet, consumers face very few incentives to change their dietary habits for adopting such unfamiliar (and often repulsive) foodstuff, especially as most of them don't perceive the importance and urgency of such a switch (Séré de Lanauze, 2015; Shine, 2021). For my postdoctoral research, I now intend to keep working on consumer-level barriers to the adoption of such discontinuous food innovations. Based on a broad range of complete protein products, I will assess the importance consumers place on attributes such as: (1) appearance; (2) taste combinations; (3) culturally familiar recipes; (4) nutritional composition; (5) perceived or true added value; (6) packaging's appearance, material, and texture; and (7) rational, hedonic, and other marketing messages. Besides conducting consumer-oriented research, in-depth interviews with marketers will help pinpoint the strengths, limits, opportunities, and challenges currently associated with such products. It should then help identify major contemporary trends in the agri-food sector on which innovative protein products could surf.

Providing consumers with sustainable protein alternatives that are appealing, convenient, and in line with their values is a great challenge for the food industry. It should be seen as an opportunity to prepare for the upcoming decades, which are more than likely to see many changes in both food supply practices and consumer demand. Struck by a severe health crisis, the COVID-19 epidemic has affected humans from all over the world with heavy losses. Freedoms and human lives have been taken away. Important social transitions have occurred, some of which were inevitable and have only been accelerated by the virus. It has demonstrated the immense vulnerability of human beings. Our lifestyles will now have to adapt to an increasingly fragile ecosystem, and we will have to grieve over many things. Dietary changes will most definitely figure amongst these necessary changes. Whereas some restaurants have adjusted their menu for take-out, others were forced to shut down – as curfews, travel restrictions, quarantines, and the fear of getting sick kept people at home. Shortages and distribution issues caused food prices to increase, while many people have lost their jobs or seen their income drop. As a result, it has become increasingly difficult to eat what we want, when we want, where we want, and with whom we want. The environmental crisis we are currently facing will only contribute to strengthen such disruptions in our eating patterns and dietary corpus.

If the recent scientific interest for entomophagy has been largely driven by the goal of achieving greater ecological sustainability and global food security, future motivations might also arise from a dietary health perspective (Stull et al., 2018). Nutrition is quickly gaining increasing social significance amongst the population. It is now common to see nutritionists appear in radio and television shows of all sorts, some even becoming popular public figures. Despite the rising awareness of the importance of nutrition in maintaining a good physical and mental health, medical discoveries in this field are still in their infancy. Scientists are only starting to assess how food affects human bodily functions. Notwithstanding medical advances in improving life expectancy by successfully curing a broader range of health conditions, inflammatory bowel diseases are affecting a growing proportion of the world population – for which the central role played by the gut microbiome is being increasingly recognized. Beyond helping to achieve reductions in obesity rates and its related diseases, alternative and healthy sources of complete proteins might soon be linked with other benefits for the human body. Meanwhile, taxing unhealthy foodstuffs could be a way to help cover the social costs linked to the treatment of diet-related diseases. It could help fund research, innovation, and communication costs linked to the development and commercialization of healthy foods – as we already know that their consumption can help preventing many avoidable diseases.

Food for thought…

Appendix A – Concordia Food Coalition working group application

CONCORDIA FOOD COALITION WORKING GROUP APPLICATION

GENERAL PROJECT INFORMATION
Group/Project Name: Chirps for Thought
Project Start Date: September 1st 2017

CFC'S WORKING GROUP LIAISON
Internal Contact Information (Liaison person(s) for the group and personal phone)
Name(s): Didier Marquis
Phone #: 514-503-3204
Email: didier.marquis@concordia.ca

PROJECT ABSTRACT
Edible insects are becoming widely recognized as a sustainable alternative to conventional meat, which not only causes important environmental stress, but its prices are also projected to increase substantially in the upcoming years. Chirps for thought aims to lay the groundwork for the widespread adoption of edible insects in the Concordia community by challenging perceptual and economic barriers. Its objectives are threefold, namely to: 1) implement a participative insect farm using food waste as feed and producing organic fertilizer for community plant growers; 2) develop educational activities using insect rearing environments to improve food awareness; and 3) build an alternative food network that promotes production exchanges between community farmers. Edible insects offer the chance for more people to engage in urban agriculture. They also hold a great pedagogical potential. This project shall provide crucial insights on the identification of successful strategies and tools allowing for the adoption of edible insects as a locally produced source of protein for the Concordia community and the urban population in general.

CFC VALUES & MANDATE
Considering the CFC's approach, how will your working group promote/contribute to grassroots food system change?
This working group aims to make an efficient use of organic waste in order to produce a nutritious source of protein on campus as well as rich organic fertilizer for food growers in the community. Edible insects constitute a sustainable alternative to the resource- and energy-intensive

conventional livestock industry, allowing to save freshwater, human food and agricultural land while lowering greenhouse gas emissions. A critical food pedagogy approach is used to increase awareness towards the environmental-, social- and health-related impacts of everyday eating habits. Brochures, intro sessions, meetings and conferences will be implemented in order to make students more oriented towards sustainability. This project will contribute to Concordia Food Coalition's mission of "*promot[ing] and facilitat[ing] a transition to a more sustainable food system in collaboration with organizations at Concordia and beyond*".

EVENT ORGANIZING
Give an example of an event your group might organize or provide the titles and descriptions of any workshops or presentations that your group could offer on request or for future events.
Workshop Title: Introduction to insect eating
Workshop Description: Providing information about entomophagy (insect eating), the potential of urban insect farms in enhancing food security, and instructions to build a sustainable insect farm at home using domestic food waste as feed as well as preparation and cooking tips.

STUDENT/COMMUNITY ENGAGEMENT
How will you engage undergraduate students and/or the Concordia community and how will this project benefit them?
Four volunteers each working two hours per week will be recruited to assist the project leader by playing an essential role in feeding, cleaning, and other maintenance activities of the insect farm. Eventually, the more experienced will be asked to lead educational activities. As school programs have been proven effective in altering participant's diets, both graduate and undergraduate students should benefit from an improved food sense, allowing greater well-being through individual and communal empowerment. The whole Concordia community will also benefit from educational activities as well as an alternative source of animal protein which will be produced and sold on campus. Events and workshops will be promoted through posters, flyers and social media to ensure the greater participation of every actor.

How do you integrate new members?
Recruitment will be made through online and on-campus postings. Volunteers will be trained to know how to operate the insect farm and, later on, to be able to lead educational activities. Other members will be asked to help with organization, paperworks, social media activities, and interaction with other working groups. If positions are to be filled, an open meeting will be held and all members will have the opportunity to apply.

PROMOTION INFORMATION
Please write a short 50 word description of your group for the CFC's promotional materials and website.
Chrips for thought aims to lay the groundwork for the widespread adoption of edible insects in the Concordia community by challenging perceptual and economic barriers. Its participative insect farm using food waste as feed and producing organic fertilizer for community plant growers is used to develop educational activities improving food awareness and to build an alternative food network that promotes production exchanges between community farmers.

If your group/project has a logo, pamphlet, flyer, zine or any other outreach materials, please attach them with this application.

CFC PROJECT SUPPORT

What kinds of non-financial support would you like from the CFC?

The CFC could help find a space to implement the insect farm. It could also help promote visibility, finding partners and developing the alternative food network. CFC offices and supplies would be useful to hold meetings and produce promotional material.

FINANCES & BUDGET

Total Amount Requested: 4,650$

Table 24. Concordia Food Coalition Chirps for Thought working group budget

Expense Description	*Expected Amount*	*Estimated date*
Build insect farm	***$1000***	***September***
Processing material: Freezer, hot plate, dehydrator, grain mill, vacuum sealer, hermetic sealed bags, scale	*$1000*	*October*
Website design & hosting	*$250*	*Sept - Oct*
Promotional video	*$200*	*Sept*
Banner	*$50*	*October*
Posters	*$50*	*October*
Pamphlets	*$100*	*November*
Coordinator honorarium	*$2000*	*Sept - Dec*
Revenue Description		
Insect sales: insect production revenues will allow us to attain self-funding for all activities. It will ensure the long-term realization of educational activities, alternative food network, promotional activities, conferences and events as well as efficient coordination of volunteers and activities.	*1000$/ month*	*First harvest in December*

Appendix B – Sustainability Action Fund application

Your Name: Didier Marquis
Full Project Name: Chirps for Thought
Date of project completion: Recurring
Amount Requested: 1500$

Project Abstract (~250 words)
Edible insects are becoming widely recognized as a sustainable alternative to conventional meat,which not only causes important environmental stress but its prices are also projected to increase substantially in the upcoming years. Chirps for Thought is a CFC working group aiming to lay the groundwork for the widespread adoption of edible insects in the Concordia community by challenging perceptual and.economic barriers. Its objectives are threefold, namely to: 1) implement a participative insect farm in the basement of the Hall building using food waste as feed and producing both edible insects and organic fertilizer for community plant growers; 2) develop educational activities allowing for people to get familiarized with edible insects; and 3) build an alternative food network that promotes exchanges between student groups. Edible insects offer the chance for more people to engage in urban agriculture, while holding a great pedagogical potential. The creation of an alternative food network will also help building bridges between different working groups on campus. This project, beginning in fall 2017, shall provide crucial insights on the identification of successful strategies and tools allowing for the adoption of edible insects as a locally-produced source of protein for the Concordia community and the urban population in general.

BROADER VISION
The Bigger Picture (~500 words)
Livestock farming accounts for 18% of greenhouse gas emissions and uses 70% of all agricultural land as well as 8% of freshwater reserves. As global meat demand is expected to double by 2050, supply practices must be adapted to the reality of shrinking resources. Edible insects are gaining important recognition from the United Nations and other groups of experts as a sustainable alternative to the current meat industry. While offering superior nutritional value than conventional livestock, insects' cold-blooded organisms are highly efficient food converters, its farming requiring very little water and food while producing minimal pollution and waste. With low

material requirements, insect rearing has traditionally provided great livelihood opportunities, their short lifespan and high breeding rate ensuring outstanding productivity. Despite these benefits, and entomophagy's potential to sustainably enhance food security, very little attention has been dedicated towards integrating this practice at the city scale. This is particularly important considering that two thirds of the world's population are projected to live in cities by 2050. An intelligent use of urban organic waste can be achieved through insects' omnivorous diets, a promising solution to help reach governmental objectives of banning organics from landfills. Moreover, since insect rearing requires very little space, it can improve urban populations' food security as a locally produced source of protein. Nevertheless, Westerners' aversion for insects remains the primary obstacle to the popularization of entomophagy, which is why investors currently focus on developing insect-based animal feed, providing important environmental and ethical benefits as compared to traditional feed. Another problem is the fact that edible insects are currently highly expensive products. In order to gain both public and private interest for entomophagy, we therefore must find strategies to effectively overcome perceptual and economic barriers related to insect production and consumption, such as urban organic waste upcycling and getting the population familiarized with edible insects.

My project attempts to leverage Western societies' obsession with nutrition and growing interest in urban agriculture in order to promote sustainable systems that lead to greater food security. My main objective is to identify effective pathways for the democratic integration of insect farming in existing urban agriculture networks. Microbreweries', roasters', and cafes' transformation processes generate large amounts of pre-consumer organic waste, a potentially highly valuable and sanitary resource for insect growers due to its traceability. While reducing greenhouse gas emissions associated with landfilling, upcycling such products could sustainably help lower insect production costs and ultimately improve its widespread accessibility. To close the loop, insect frass (i.e. excrements and shed skins) can be used as an organic fertilizer, having been shown to stimulate plant growth and improve their immunity. I will work on the implementation of an alternative food network transforming organic waste into food resources and devoted to improving urban dwellers' acceptance of edible insects. Getting urban farmers and consumers involved in workshops and other educational activities to gain information about sustainable urban food systems and learn how to grow and cook with insects at home will hopefully trigger instinctual realignments with insects and help overcome the aversion associated with entomophagy. As these discussions reach a wide-ranging public—simultaneously relating to environmental, food security, health, and poverty concerns—I shall seek ways to broadly disseminate this project. With the rising social significance of dietary health and its consequent increase in communal engagement, food consumers today play an important role in influencing public opinion. Therefore, I wish to harness new media as an organizational device to support mobilization and social change, and as an analytic tool offering opportunities to better assess consumer behavior.

Urban entomophagy appears as an opportunity to reconnect city dwellers with the food they eat, thus promoting mindful eating habits in which individuals bear in mind factors such as health and taste, as well as altruistic values of social and environmental responsibility. In the short run, Chirps for Thought aims to lead to changes in students' values, knowledge, and abilities about food. Then, in the medium run, to induce deviations in eating behaviors. The final objective is to influence participants' health condition and the sustainability of food systems. This project will be permanent. SAF will mainly contribute to the implementation of the cricket farm, which shall then allow for this project to be financially independent as revenues from the insect farm will be used to expand its outreach and operational activities.

Project Goals (~250 words)
Chirps for Thought is a sustainable initiative that is both operational and educational. Outreach activities using moveable insect rearing environments will be organized and an web-based interactive platform will be implemented to enable a productive public dialogue on urban insect farming and entomophagy. The creation of an alternative food network will allow to build bridges between different working groups, such as the Hive Café, le Frigo Vert, la Coopérative des brasseurs illuminés, le Campus Potager, Vermicycle, and the Concordia Farmers' Market. The insect farm will enable nutrient cycling and allow it to close the loop of a social economy model. On-campus organic waste such as coffee and beer transformation by-products will be used to feed mealworms and crickets. First, edible insects will be produced and sold for human consumption, either whole and dehydrated or powdered and used as a nutritious ingredient for recipes. Second, the frass-enriched (i.e. excrements and shed skins) substratum will also be sold (or traded) as a very rich fertilizer to stimulate plant growth and improve plant immunity. Insect and fertilizer production revenues will eventually allow to attain self-funding and therefore ensure the long-term maintenance of the farm and the realization of all its related activities.

1) Short-term goal: Investigate on how organic waste management and community engagement in urban insect farms can lower production costs on campus:

   I will implement an urban insect farm promoting community engagement and sustainable food waste management, producing organic fertilizer for community plant growers and edible insects to be consumed on campus.

   a) Build the insect farm

   § Total space required for mealworm farm (two vertical shelved each housing 12 bins): 2m x 5m x 2m
   § 2 breeding boxes using 90 litre plastic storage bins each housing 60 crickets for activities outside the farm
   § Materials: *Plastic bins, steel mesh, egg crates, mosquito net, heating mats, shelves, fan, table, mister, feeding trays, peat moss, breeding boxes, larvae*

   b) Plan the production calendar and initiate cricket colonies

   § Partner with on-campus food waste suppliers
   § Total feed required: 104 kg per month[22]
   § Total planned production: 52 kg per month
   § Dry weight production: 52 kg / 3 = 17,3 kg per month[23]

   c) Implement processing facilities

   § A freezer to kill insects without pain and preserve organic feed
   § A hot plate to boil insects in order to eliminate potential pathogens
   § A dehydrator to eliminate humidity for enhanced preservation
   § A grinder to turn insects into fine powder

[22] Estimated with a feed conversion efficiency of 2:1

[23] Even though they are already very conservative numbers, these estimates have a relatively high percentage of uncertainty, depending on successful colony densities, feed quality and mortality rate

d) Build web-based platform

§ My project will be continuously documented with multimedia content

§ Enabling consumers to react about their experience with insects (reaction, recipes, thoughts, etc.)

e) Harvest first insect colonies

§ When ready to harvest, insects are collected and frozen for 24 hours. They are then boiled for five minutes and dehydrated at 70 degrees Celsius for 10-12 hours. They can then be ground, and sealed in plastic bags.

2) Medium-term goal: Evaluate the potential of insect rearing facilities as pedagogical tools:

I will develop educational programs in order to overcome the reluctance towards edible insects and inform about sustainable food systems. Insect rearing environments will be used to familiarize people with insect farming and allow them to taste insect-based food, while increasing self-awareness around the environmental, socioeconomic and health-related impacts of everyday food choices. These activities are expected to help decrease the aversion towards edible insects.

a) Elaborate interactive educational activities for different age groups

§ Workshops centered on 1. Learning how to sustainably grow insects at home; 2. Gaining knowledge in cooking with insects; and 3. Explaining how insect farming can be integrated in urban agriculture networks.

§ Explain the benefits of insects as sustainable alternatives to conventional meat and their potential as a locally-produced foodstuff for urban population

§ Inform about cricket and mealworm diets, how they breed and their living environment

§ Multi-sensorial activities allowing to see, touch, hear and taste crickets and mealworms

§ Insect feeding activities (observe what they like and don't like)

b) Design pamphlets with key information

§ Short version for promotion activities

§ Longer version to hand-in during educational activities

c) Create observation sheets for data gathering

§ Develop semi-structured interviews and efficient measures of eating behavior such as food frequency questionnaires as outcome measuring tools to evaluate the success of personal involvement with insects as a strategy to overcome neophobia (reluctance towards unknown foods)

§ Determine if people would consider crickets as an alternative to conventional meat rather than a mere dietary supplement

§ Evaluate the potential of insect-based pedagogical activities in enabling food empowerment

3) Long-term goal: Explore how insect domestication can build bridges between different working groups and allow for a wider range of actors to engage in urban agriculture

I will implement an alternative food network to promote production exchanges between urban farmers engaging in different activities and to further democratize entomophagy.

a) Facilitate production exchanges between urban farmers
§ Develop organization tools allowing insect farmers to trade edible insects and rich fertilizer against other food/feed products
§ Create a sense of community by building bridges between producers and consumers
§ Enable shorter food-supply chains in an urban environment

b) Evaluate its success rate
§ How new actors are successfully introduced in urban agriculture networks
§ Its effect on urban farmers' general perception towards edible insects

PROJECT INFORMATION

Outreach and Student Engagement (~500 words)

Chirps for Thought is an initiative aiming to improve the quality of student life on campus by offering the chance for many to engage in insect farming, selling sustainable and healthy locally-produced edible insects, and proposing educational activities to get familiarized with entomophagy and insect farming. We are planning for an opening day in fall 2017, as soon as we have confirmation of funding from the different stakeholders. The Concordia Food Coalition will help promote the project visibility and recruitment of four volunteers each working two hours per week. They will assist the two project leaders by playing an essential role in feeding, cleaning and other maintenance activities of the insect farm. Eventually, the more experienced will be asked to lead workshops. As school food programs have been proven effective in altering participant's diets, both graduate and undergraduate students should benefit from an improved food sense, allowing greater well-being through individual and communal empowerment. The whole Concordia community will also benefit from educational activities as well as an alternative source of animal protein which will be produced on campus and offered in organic restaurants and cafés. Therefore, this project includes both short- and long-term engagement. Food eaters and people interested in urban farming, food security, and sustainability are targeted as a community. Events and workshops will be promoted through posters, flyers, social media, and personal recruitment to ensure greater visibility and participation, with a special attention to reach students that are not very connected in the community.

Culture of Sustainability (~250 words)

This project makes an efficient use of organic waste management in order to produce a nutritious source of protein on campus as well as rich organic fertilizer for food growers in the community. Edible insects constitute a sustainable alternative to the resource- and energy-intensive conventional livestock industry, allowing to save freshwater, human food and agricultural land while lowering greenhouse gas emissions. A critical food pedagogy approach is used to increase awareness towards the environmental-, social- and health-related impacts of everyday eating habits. Brochures, intro sessions, meetings and conferences will be implemented in order to make students more oriented towards sustainability. Moreover, many partnerships will be created with other student working groups in order to build a circular economy network. This project will contribute to Concordia Food Coalition's mission of "*promot[ing] and facilitat[ing] a transition to a more sustainable food system in collaboration with organizations at Concordia and beyond*", while providing many experiential learning opportunities.

Stakeholders

1- *Concordia Food Coalition*: As part of a working group, I will benefit from crucial organizational support, visibility and help with finding volunteers.
2- *EHS (Environmental, Health, and Safety) Program*: Faisal Shennib, environmental coordinator, is currently securing a space for the insect farm. The EHS program can also help with funding.
3- *CCSL*: I have recently submitted a *Special Project* application in order to secure funding.
4- *Satoshi Ikeda*: Prof. Ikeda is my main advisor. He supports this project and can bring important help through his expertise in social economy and sustainable agriculture, as well as providing crucial advice as he is deeply engaged in community food movements.
5- *Fondation David Suzuki*: In partnership with Dr. Louise Hénault-Éthier, chief of scientific projects and biologist specialized in entotechnologies (using insects to manage organic waste), I am currently working on laboratory experiments to identify an optimal mealworm feeding diet using organic waste. Many years ago, she implemented vermicomposting in the Concordia Greenhouse and she accepted to give all the help for the success of this project.
6- Jean-Philippe Lessard: Prof. Lessard is a biologist at Concordia who has expertise in entomology. He accepted to act as an external collaborator if ever his help was needed to improve the cricket farm.
7- *Alvéole*: Alex McLean, founder of an urban beekeeping initiative who offers educational services to overcome the fear of bees in cities, offered his team's help with implementing awareness activities for this project.
8- *Hive Café*: Could supply coffee grounds for insect feeding
9- La Coopérative des Brasseurs Illuminés: Could supply brewery waste (spare grains) for insect feeding
10- *Le Frigo Vert and Concordia Farmers' Market*: Could sell powdered and whole edible insect
11- *Greenhouse* and *Le Campus Potager*: Could use fertilizer made with insect frass to stimulate plants' growth and immunity system.

Timeline

Table 25. Sustainability Action Fund insect farm activities' timeline

Type of Activity - Task	Deadline	Group Member in Charge
Implement insect farm	*November 30th, 2017*	*Didier*
Design website	*December 15^{th}, 2017*	*Didier*
Identify on-campus partners and "retailers"	*December 31^{st}, 2017*	*Didier*
Prepare workshops	*January 30^{th}, 2017*	*Laura*
Engage in promotional activities	*February 15^{th}, 2017*	*Didier*
Design pamphlets	*February 31^{st}, 2017*	*Laura*
Create outcome measuring tools	*March 15^{th}, 2017*	*Didier*
Organize events and conferences	*April 31^{st}, 2017*	*Laura*
Build alternative food network	*May 15^{th}, 2017*	*Didier*

REPORTING AND ACCOUNTABILITY
Project Transparency (~250 words)
I will stick to my budget and keep track of every expense with receipts. Financial reports will be available online. Contact information will be provided and I will encourage students and community members to leave comments and feedback.

SAF Promotion (~150 words)
SAF would be promoted by having its logo on the website and printed on every flyer, pamphlet and banner. SAF would be invited at every event and a special thanks would be expressed in each publication, workshop, and interview.

Team Roles and Responsibilities (100 words max per member)
Didier is the project coordinator. He will be responsible for implementing the insect farm, designing the website, creating partnerships, engaging in promotional activities and creating outcome measuring tools. Laura will help with the elaboration of educational activities, designing of pamphlets as well as the organization of events and conferences. Imogen will help with the maintenance of the farm and workshops.

FINANCES
Total Amount: 1500$

Where do you plan to allocate SAF funding?

- Outreach and Marketing
- Equipment Purchase

Budget

Table 26. Sustainability Action Fund insect farm budget

Expense Description	Estimated Cost	Timeline for spending
Build insect farm: Plastic bins, steel mesh, egg crates, mosquito net, heating mats, shelves, fan, table, mister, feeding trays, peat moss, breeding boxes, larvae	*$1000*	*March*
Processing material: Freezer, hot plate, dehydrator, grain mill, vacuum sealer, hermetic sealed bags, scale	*$1000*	*April*
Workshops: Material to build movable insect farms, plates, cooking material, ingredients for insect-based recipes, beverages Website design & hosting	*$500*	*May – June*
Website: Design, hosting, how-tos of growing insects (paper instructions and video clips)	*$250*	*September*
Outreach: Banner, posters, pamphlets, promotional video	*$250*	June
Distribution: Edible insect powder, whole dehydrated insects, fertilizer	*$250*	*August*
Guest speaker: Dr. Louise Hénault-Éthier (David Suzuki Foundation) will give a talk on how edible insects can be used in organic waste management	*$100*	*September*
Coordinator honorarium: To cover period of activities until revenues from the insect farm start flowing: building the farm, breeding insects, preparing workshops, photo/video documentation, recruiting volunteers, building partnerships with other working groups	*$1600*	*April to November*

Other Sources of Funding

Table 27. Sources of funding for on-campus insect farm

Revenue Source	Amount Requested	Approved? (Yes/No/Awaiting response)
Concordia Food Coalition	*$1,000*	*Yes*
CCSL	*$1,250*	*Yes*
Integrated Residual Materials Management Program	*$1,200*	*Awaiting response*
Revenues from the sale of insects and fertilizer	*$1,000/month*	*Starting April 2018*

Funding Strategies (~250 words)
The sum of 1000$ is essential for the implementation of the cricket farm. Another 1000$ will later be necessary for the implementation of processing facilities, which will allow for the production of locally-produced edible insects as an independent source of revenues. If no funding is awarded, the insect farm will not be able to enter the production phase. If only partial funding is awarded, outreach, marketing, and educational activities will have to remain on hold until revenues from the farm start flowing. Once the project gets settled (April 2018), insect and fertilizer production revenues of about 1,000$ per month will allow it to attain self-funding for all following insect-related activities. It will ensure the long-term realization of workshops and other educational activities, alternative food networks, promotional activities, conferences and events as well as efficient coordination of volunteers and activities. Obtaining CCSL funding would allow to optimize the insect farm and secure access to space in the greenhouse.

Other Resources (~150 words)
If ever things get complicated with securing a space, SAF could help finding an alternative space. It could also help promote visibility, finding partners and developing the alternative food network with other student working groups.

Appendix C – Mitacs Accelerate project (Alvéole)

Title of project:	Chirps for thought		
Number of Internship units:	3		
Keywords to identify reviewers:	Edible insects, entomophagy, food pedagogy, urban farming, sustainability, consumer behavior		
Project priority sectors:	1st Priority Sector	2nd Priority Sector	3rd Priority Sector
	Agriculture & Food	Sustainability & the Environment	Education
Project purpose:	(x) Creation of new materials, devices, or products (x) Creation of new processes or services		

Partner organization(s)	Province of organization	Partner Legal Status
Alvéole	Quebec	For Profit Canadian Private Corporation

Project title: Chirps for thought

Research Abstract (Approx. 150 words):
Edible insects are becoming widely recognized as a sustainable alternative to conventional meat, which not only causes important environmental stress but its prices are also projected to increase substantially in the upcoming years. This project aims to lay the groundwork for the widespread adoption of edible insects in urban societies by challenging perceptual and economic barriers. Its objectives are threefold, namely to: 1) implement a participative cricket farm in Montreal making an efficient use of food waste and assessing consumer behavior; 2) develop educational programs using moveable insect rearing environments to improve food awareness; and 3) provide services for customized installation of cricket farms and build an alternative food network that promotes production exchanges between urban farmers. Edible insects offer the chance for more people to engage in urban agriculture. They also hold a great pedagogical potential. This project is essential for my PhD research as it shall provide crucial insights on the identification of successful strategies and tools allowing for the adoption of edible insects as a locally-produced source of protein for urban populations. *Alvéole* would also greatly benefit from this project by diversifying both their insect domestication and educational services, while expanding their range of insect by-products on the market.

Background and review of relevant prior work (minimum 500 words):
Due to demographic growth, intensification of urbanization processes and evolution of diets, global meat demand is expected to roughly double by 2050 (Gouel & Guimbard, 2017). Subsequently, we are confronted with the insufficiency of world resources. Livestock farming is already accountable for 18% of all greenhouse gas emissions, consumption of 8% of freshwater reserves and 70% of all agricultural land use (Steinfeld et al., 2006). As an alternative to conventional meat, entomophagy – or insect consumption – has been enthusiastically supported by the Food and Agriculture Organization (van Huis et al., 2013). Insects' cold-blooded organisms allow for a high feed conversion efficiency, requiring very little water and feed while producing minimal pollution and waste (Oonincx et al., 2010; van Huis, 2013). Many species, such as crickets, have a superior

nutritional value than conventional livestock based on their content in proteins, essential amino acids, fibres, vitamins and minerals (Rumpold & Schlüter, 2013). Moreover, their short lifespan and high breeding rate ensure outstanding productivity (Collavo et al., 2005). Due to its minimal material requirements, insect rearing can provide livelihood opportunities to many people (Belluco et al., 2013; van Huis & Vantomme, 2014). Considering that food prices are expected to keep rising in the upcoming decades (Wise, 2013), insect rearing thus clearly has a high potential in assuring both greater food security and sustainability (Looy et al., 2014; van Huis, 2015). But in order for edible insects to be seriously considered as a sustainable alternative to macro livestock in Western societies, its production and consumption must be democratized in order to prevent exclusionary processes.

Urban entomophagy appears as an opportunity to reconnect city dwellers with the food they eat, thus promoting mindful eating habits in which individuals bear in mind factors such as health and taste, as well as altruistic values of social and environmental responsibility. The rising popularity of urban agriculture has enabled many people to produce their own source of food, allowing for greater food security through self-sufficiency. Based on short supply chains, these alternative food movements build bridges between producers and consumers (Blay-Palmer, 2010). They contribute to alleviate the pressure on energy- and resource-intensive globalized food systems. Yet, they do not intrinsically constitute a democratic mode of governance by marginalizing much of the population (Allen, 2010). Insect rearing however requires very little space and no access to a garden. It can enable the production of a locally-produced source of protein for urban dwellers. People engaging in domestic insect production can both trade micro livestock as foodstuff and insect residues, which constitute a rich organic fertilizer. It thus allows to further widen production exchanges between urban farmers while promoting the popularity of entomophagy in alternative food networks. Additionally, an intelligent use of domestic food waste can be achieved through insects' omnivorous diets, lowering the pressure on urban landfills and thereby diminishing both public expenses and greenhouse gas emissions (Lundy & Parrella, 2015). However, to gain public interest, we must first overcome the fear and disgust of insects resulting from neophobia – a human reluctance to eat unfamiliar foods as a defence mechanism against poisoning (Verbeke, 2015).

Through this project, I will delve into cross-section action research on food studies and consumer behavior in order to identify effective strategies and tools allowing for the integration of insects as a self-reliant source of alternative animal protein for urban populations. Its holistic approach isn't merely intended at getting people to try edible insects once but rather at suggesting appropriate practices leading to their integration in everyday diets by overcoming both barriers of price and perception. The levelling effect provided by innovative interdisciplinary studies will lay the groundwork on the potential of: 1) insect farms to lower feed costs through community engagement, while assessing consumer behavior; 2) educational programs using moveable insect rearing environments to improve food awareness and alter eating behaviors; and 3) insect farming in allowing for a wider range of actors to engage in urban agriculture and enhance community food security through production exchanges. Whereas the rising popularity of urban beekeeping has successfully reduced populations' fear of bees (Moore & Kosut, 2013), familiarizing one's self with edible insects could also lead to their greater acceptance (Tan et al., 2015).

My research will be pursued at Concordia University's Centre for Interdisciplinary Studies in Society in Culture. This project is supervised by Jordan LeBel (Marketing), whose expertise relies on sensory marketing and consumer behavior in order to promote mindful food choices. My PhD supervisory committee also consists of Satoshi Ikeda (Sociology) and Elizabeth Miller (Communication Studies). Prof. Ikeda specialises in social economy and sustainable agriculture, besides being deeply engaged in community food movements. Prof. Miller has done extensive interdisciplinary research on the political ecology of food and on methods of going public.

General objective of the research project broken down into sub-objectives, activities, themes, or subprojects, as applicable:

This project will be centered on participatory action research (Kindon et al., 2007), in which reflection remains ubiquitous but challenges scientific positivism by being oriented towards empowerment and social transformation. Throughout the past year, in order to develop applied abilities to efficiently bridge the gap between theory and practice, I have successfully bred, reared and processed my own crickets, based on well-documented methods (Clifford & Woodring, 1990; Dossey et al., 2016; Patton, 1978). I will now work in partnership with *Alvéole*, a Montreal-based urban beekeeping company to:

1) Investigate how community engagement can serve as a viable strategy for the development of urban insect farms, especially as a way to lower production costs and evaluate the perception of entomophagy in Quebec:
   I will implement an urban cricket farm promoting community engagement and sustainable food waste management, while producing organic fertilizer for community plant growers. A web-based platform will be created to assess stakeholder behavior while enabling a productive public dialogue on entomophagy and promoting social change.

2) Evaluate the potential of moveable insect rearing facilities as pedagogical tools:
   I will develop educational programs centered on social cognitive theory – which has been found to decrease neophobia (Berlin et al., 2013) – and critical food pedagogy (Sumner, 2015) – aiming to inform about alternatives to unsustainable food systems – by using moveable insect rearing environments to familiarize people with cricket farming and allow them to taste insect-based food, while increasing self-awareness around the environmental, socioeconomic and health-related impacts of everyday food choices.

3) Explore whether insect domestication can overcome adoption barriers towards entomophagy while allowing for a wider range of actors to engage in urban agriculture:
   I will implement services providing customized cricket farm installation, allowing for greater energy efficiency through the on-site use of organic waste for insect feed while producing a healthy and sustainable source of protein. An alternative food network will be created to promote production exchanges between urban farmers engaging in different activities.

Details of internships or subprojects:

1) Cricket farm and online platform
   Build breeding and rearing boxes and set up a controlled environment (temperature, humidity, light, ventilation)
   - 2 breeding boxes using 90 litre plastic storage bins each housing 60 crickets
   - 8 rearing boxes of 1m x 3m x .5m which can each house 30,000 adult crickets
- Total space required for Phase 1: 2.2m x 6.2m x 1.2m

- Materials: Cloroplast, wood, steel mesh, egg crates, mosquito net, water dispensers, plastic feeding boxes
- Removable bottom allowing for easy weekly cleaning
- Customized structure allowing to superimpose 2 rearing boxes
- Closed environment made of plastic wall panels
    - Electric heater, humidifier, lamps, fan

Plan the production calendar and initiate cricket colonies (Phase 1)

- Find food waste suppliers in the community who will be offered cricket manure (a rich fertilizer) as a compensation for their participation
    - Food waste can be frozen for greater preservation
    - Buy soy flour and skim milk as a protein supplement for crickets
    - Total feed required[24]: 212 kg per month
- Total planned cricket production[25]: 106 kg of cricket per month
- Dry weight cricket production: 106 kg / 3 = 35 kg per month
- Total planned sales: 4,200$ per month
  *However, these estimates have a relatively high percentage of uncertainty, depending on successful colony densities, feed quality and mortality rate.

Implement processing facilities

- A freezer to kill crickets without pain and preserve organic feed
- An electric stove to boil crickets in order to eliminate potential pathogens
- A dehydrator to eliminate crickets' humidity for enhanced preservation
- A grinder to turn crickets into powder
- A vacuum sealer for packaging

Develop initial brand identity, marketing strategies, promotion activities and packaging design

- Develop marketing strategies centered on taste, environmental sustainability and health benefits
- Make an efficient use human resources available at *Alvéole*
- Use social medias as promotional platforms
- Find retail stores and set online sales

Build web-based platform

- Used for online sales, research dissemination, mobilization and data gathering
- My research will be continuously documented with multimedia content and be made available online
- Consumers will be strongly encouraged to react about their experience with insects on an interactive interface (reaction, recipes, thoughts, etc.)

Engage in social research to evaluate the potential of emtomophagy in Quebec

24 estimated with a feed conversion efficiency of 2:1

25 for crawling space available in 8 boxes + 1440 egg crates of $900 cm^2$

- Use of online surveys to collect data regarding the aversion or interest of different age cohorts and ethnic groups towards entomophagy
- A qualitative analysis of consumers' reaction on the interactive interface will allow to assess new consumers' reaction (neophobia/neophilia)
- Use of sales analysis to evaluate the efficiency of different marketing strategies used to target different age cohorts (e.g.Taste-oriented vs reflection-oriented strategies, self-centered vs for the greater good)
- Compare cost and time efficiency of using community food waste as insect feed

Harvest first cricket colonies

- When ready to harvest, insects are collected and frozen for about two hours. They are then boiled for five minutes and dehydrated at 70 degrees Celsius for 10-12 hours. They can then be ground, then sealed in plastic bags.

Benefit to the intern:

The realization of this first objective will lay the foundations for sustainable cricket farms in urban communities that contribute to further democratize entomophagy. Insights will be provided on the benefits of making an effective use of emerging technological methods for academic research, investigation and dissemination that allow to reach and exchange with audiences from outside the academic world. Assessing and understanding consumer behavior towards edible insects will allow us to identify efficient strategies to put forward in order to overcome perceptual barriers and increase the popular interest towards entomophagy.

2) Educational programs

Built moveable cricket rearing environments

- Using 90 litre plastic storage bins with breeding colonies (see Objective 1)
- Multi-sensorial installation allowing to see, touch, hear and taste crickets

Elaborate interactive educational activities for different age groups

- Implement effective nutrition education seeking to enhance motivation, provide knowledge and skills, and create efficient supports (Contento, 2015)
- Critical food pedagogy introducing notions of food sustainability, food security, urban agriculture, climate change and human health through contextualized narratives
- Explain the benefits of insects as sustainable alternatives to conventional meat and their potential as a locally-produced foodstuff for urban population
- Inform about cricket diets, how they breed and their living conditions in the wild versus domesticated
- Edit a short film: the traditional use of edible insects in different communities around the world
- Children: cricket feeding activities (observe what they like and don't like)
- Adults: discuss the possibilities of implementing a cricket farm at home, producing a rich fertilizer with cricket residues and integrating alternative food movements while making an efficient use of domestic food waste
- Tasting activities

Develop cricket recipes

- Use both whole roasted crickets and cricket powder
- Differentiate sweet and salty recipes

Design pamphlets with key information

- Short version for promotion activities
- Longer version to hand-in during educational activities

Create observation sheets and interviews for data gathering

- Build semi-structured interviews and develop efficient measures of eating behavior in order to evaluate the success of personal involvement with insects as a strategy to overcome neophobia
- Evaluate success rates of gastronomy and familiarization as strategies to overcome the reluctance towards edible insects
- Determine if people are willing to consider crickets as an alternative meat (popularity of salty recipes)
- Evaluate the potential of insect-based pedagogical activities in enabling food empowerment

Promote educational services

- Contact current *Alvéole* clients to inform them about this new program
- List target customers (first elementary schools, then sustainable enterprises) and send virtual flyers
- Elaborate online marketing strategies

Run the program

- Realize at least one activity with an adult group and one with a children group
- Evaluate and propose adjustments

Benefit to the intern:

The realization of this second objective will allow me to evaluate the potential of moveable insect rearing facilities as pedagogical tools to address the impact of our daily food choices. It will provide insights on the benefits of using action research in food studies as a way to enable critical knowledge mobilization, as well as a better understanding of the importance of educating tomorrow's consumer and shaping attitudes and habits early on in order to lead to social change regarding food habits.

3) Installation services and alternative food network

Identify suppliers

- Take into consideration reliability, convenience, affordability and quality

Price services

- Installation: according to farm dimensions
- Processing services for medium-scale farms allowing greater traceability and increasing food safety through standardized processing
- Define area to be covered

Promote services

- First focus on schools, then on enterprises and households
- Identify key marketing strategies and platforms to be used
- Offer package deals combining the installation of beehives and insect farms
- Contact current *Alvéole* clients to inform them about these new services

Implement an alternative food network to facilitate production exchanges between urban farmers

- Web-based and self-managed platform
- Allowing cricket farmers to trade edible insects and rich fertilizer against other foodstuff, including honey produced by other *Alvéole* clients
- Create a sense of community by building bridges between producers and consumers
- Enable shorter food-supply chains in an urban environment

Evaluate how domestication affects insect farmers' relation to entomophagy

- Develop semi-structured interviews and food frequency questionnaires as outcome measuring tools to evaluate the effectiveness of personal involvement with insects on perceptual barriers

Secure funding to expand urban cricket farm

- The objective being to strengthen public interest towards edible insects, demand is expected to increase
- Prepare promotional video detailing all insect-related activities
- Calculate corporate budget with actual and projected incomes and expenses
- Contact governmental and private agencies

Benefit to the intern:

The realization of this third objective will allow me to evaluate the success of domestication as a strategy to overcome reluctance and enable instinctual realignments with edible insects. It will offer crucial insights on potential avenues to further democratize urban agriculture by allowing for the integration of a wider range of actors in these networks while fostering entomophagy as a common practice. Analyzing how community food security can be addressed by facilitating production exchanges between urban farmers will contribute to tackle critical contemporary food challenges.

Relevance to the partner organization and to Canada:

Edible insects can contribute to alleviate the pressure on food production systems, particularly the resource and energy-intensive sector of livestock, while promoting greater food security through an efficient use of food waste. Due to their growing popularity, mass producers in North America strive to respond to the current demand. Prices for such products thus remain very high (over 40$/pound). Lowering production costs through community engagement would increase consumers' interest towards edible insects. Identifying effective marketing strategies and engaging in educational activities around entomophagy could also help increase consumer demand. Cricket-related activities will ensure *Alvéole* a reliable source of income during the cold season, when beekeeping activities are on hold. Offering the opportunity for a wider range of actors to engage in urban agriculture will increase the demand for such service providers, while promoting alternatives to alleviate the pressure on food production systems. Ethical urban food consumption constitutes both a collective and individualistic challenge. Providing the appropriate tools to make space for education about food will help today and tomorrow's consumers make healthy and sustainable food choices.

Table 28. Research costs for three internship units with Alvéole

Research Costs	Value
1. Build insect farm (2,200$), rent (1,200$), Processing instruments (1,000$), Electricity (300$), Soy flour/Skim milk (100$), Design website (200$)	$5,000
2. Rent, (1,200$), Rearing boxes (300$), Oven & cooking instruments (700$), Documentation (400$), Online marketing (500$), Film production (400$), Fertilizer packaging (300$), Travelling expenses (400$)	$4,200
3. Rent, (1,200$), Storage of material (600$), Promotional activities (600$), Travelling expenses (400$), Truck rental (1,200$), Promotional video (500$)	$4,500
Total research costs (B) - which cannot exceed $5,000 per internship unit:	$13,700

Public Project Overview:
The global meat demand is expected to roughly double by 2050. While the livestock sector monopolizes a lot of land, food and water, edible insects constitute an interesting alternative to lower environmental stress. Although almost a quarter of the world population regularly eat insects, their widespread adoption is impeded by the disgust factor and high production costs. In order to facilitate the introduction of edible insects as a locally produced source of protein for urban populations, this project will see the implementation of a cricket farm promoting community engagement assessing consumer behavior. It will also offer educational programs and provide cricket farm installation services allowing for more people to engage in urban agriculture and diversifying production exchanges between urban farmers. *Alvéole* would also greatly benefit from this project by diversifying both their insect domestication and educational services, while expanding their range of insect by-products on the market.

Appendix D – Internship at the Montreal Biodome

Fonds de recherche
Société et culture
Québec

Québec, le 26 février 2018

MARQUIS, Didier
Université Concordia
didier.marquis@concordia.ca

Objet : Complément d'information suite à votre résultat du programme Bourse de stage en milieu pratique (BSMP).

Complément d'information à la lettre d'octroi

Les membres du comité chargés d'évaluer votre dossier ont examiné 34 candidatures et classé votre demande au 2[e] rang. Ils lui ont attribué la cote « A+ », la classant parmi les demandes d'une qualité scientifique exceptionnelle. Par conséquent, le comité a recommandé son financement au Fonds Société et culture.

La recommandation du comité d'évaluation est le résultat d'un consensus de la part de ses membres, qui ont été amenés à se prononcer sur la valeur de votre demande, établie selon les critères d'évaluation suivants :

Projet de stage :	**Exceptionnel « A+ »**
Calendrier des réalisations :	**Exceptionnel « A+ »**
Milieu d'accueil et encadrement :	**Excellent « A »**

Le Fonds de recherche du Québec – Société et culture espère ainsi contribuer à l'enrichissement de votre programme de formation et vous permettre d'explorer de nouvelles perspectives dans votre domaine de recherche.

140, Grande Allée Est, bureau 470
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Projet CooleopTerre: Agriculture urbaine et économie circulaire de quartier dans Hochelaga-Maisonneuve

Contexte

La popularité des insectes comestibles grimpe en flèche depuis la parution en 2013 d'un rapport de l'Organisation des Nations unies pour l'alimentation et l'agriculture, affirmant que cette alternative durable à la viande conventionnelle représente probablement la meilleure solution aux problèmes d'insécurité alimentaire mondiale. Puisqu'on estime que la demande globale en viande devrait doubler d'ici 2050, les pratiques d'offre doivent effectivement être adaptées à la réalité des ressources naturelles limitées. Les insectes possèdent de nombreux avantages, notamment sur le point des valeurs nutritionnelles, du taux de conversion alimentaire, de l'empreinte écologique de leur production et des besoins matériels nécessaires à leur élevage. De plus, leur diète omnivore peut s'avérer une solution intelligente pour permettre une saine gestion des résidus organiques urbains, s'alignant ainsi avec les objectifs gouvernementaux de bannir l'enfouissement de ces débris recyclables dans les prochaines années. Bien qu'il est estimé que l'entomophagie (consommation d'insectes) est pratiquée par plus de deux milliards d'êtres humains dans le monde, de fortes barrières psychologiques empêchent leur adoption généralisée. De plus, les coûts de production élevés représentent un autre frein à leur introduction dans le marché nord-américain.

Projet de stage

Le projet CooleopTerre, dont je suis l'instigateur et pour lequel j'ai obtenu l'approbation du comité de direction du Biodôme, vise à s'attaquer à ces deux barrières psychologiques et économiques. En partenariat avec Blanc de Gris, faisant pousser des pleurotes en ville sur des résidus de transformation de café et de bière récoltés à même le quartier Hochelaga-Maisonneuve, ce projet vise à valoriser le riche substrat de la champignonnière et le mycélium qu'il contient en s'en servant comme ressource alimentaire pour nourrir des ténébrions. En s'associant avec le Biodôme, CooleopTerre met de l'avant un modèle d'économie circulaire de quartier. Les insectes ainsi produits pourraient éventuellement s'insérer dans la diète régulière de nombreuses espèces élevées sur place (poissons, reptiles, mammifères et oiseaux). Une fois revalorisé, le substrat final, enrichi d'exuvies et de déjections d'insectes, représente quant à lui un fertilisant naturel pouvant stimuler la croissance des plantes du Biodôme et améliorer leur système immunitaire. Un grand travail de sensibilisation et de mise en marché reste à faire avant que le créneau de l'alimentation humaine par les insectes ne s'épanouisse. Celui de l'alimentation animale représente une avenue immédiate permettant d'adresser de nombreux enjeux socio-environnementaux. Néanmoins, CooleopTerre souhaite contribuer à la promotion de l'entomophagie chez la population urbaine, non seulement en identifiant une diète économique et durable pour l'élevage d'insectes, mais également en élaborant des ateliers éducatifs visant à vaincre le dégoût et la peur des insectes et à informer le public face à leur contribution potentielle aux différents enjeux susmentionnés: sécurité alimentaire, agriculture urbaine, compostage et économie circulaire.

Ce stage, d'une durée de six mois, s'insère parfaitement à l'intérieur de mon cheminement doctoral étant donné que ma méthodologie repose sur la recherche-action, soit l'application concrète de systèmes ayant pour but de provoquer des transformations sociales afin de répondre à des enjeux précis, tout en produisant des connaissances sur l'efficacité même de l'utilisation de ces procédés. Mes études interdisciplinaires pigent dans différents champs de pratiques et de compétences (c.-à-

d. sociologie alimentaire, comportements des consommateurs et communication scientifique) afin de proposer des réponses novatrices aux questions de recherche sur lesquelles je me penche, me permettant ainsi d'identifier des stratégies efficaces pour intégrer de façon durable la production et la consommation d'insectes comestibles dans les régions urbaines comme source locale de protéines animales. J'ai développé des liens importants avec des entomologistes de la Fondation David Suzuki et du département de Biologie de l'UQAM alors que j'y ai coordonné des tests de laboratoire visant à identifier le taux de mycélium (c.-à-d. les racines de champignons) optimal à être utilisé pour l'alimentation des ténébrions meuniers. De plus, je poursuis actuellement un premier stage à temps partiel en partenariat avec l'entreprise Alvéole afin d'élargir leur gamme de produits dérivés d'insectes sur le marché ainsi qu'identifier une moulée organique et locale pour leurs poules urbaines.

Calendrier des réalisations

Le projet CooleopTerre comporte deux volets, soit un volet opérationnel et un second à vocation éducative. D'abord, il vise l'implantation d'un réseau alimentaire alternatif produisant à faible coût et avec peu de ressources des insectes comestibles ainsi que du fertilisant naturel. En outre, il a pour but d'élaborer des activités de sensibilisation permettant au public de mieux cerner les enjeux dont il est question et de combattre l'aversion culturelle envers l'entomophagie. Mon stage, se déroulant sur une période de six mois, servira à l'implantation du projet CooleopTerre. Il sera divisé en trois segments. Les mois de décembre, janvier et février seront dédiés à la mise en place des stratégies de transport de substrat de croissance en provenance des locaux de Blanc de Gris, à l'élaboration des calendriers d'élevage, à la construction des infrastructures de production et de transformation, ainsi qu'à l'établissement des procédures de stockage d'insectes et de fertilisant. Les insectes seront élevés dans des conditions respectueuses de leurs besoins biologiques, et leur abattage en fin de vie sera fait selon les procédures les plus éthiques disponibles à ce jour (c.-à-d. par congélation). Au courant du mois de mars, des tests seront effectués pour déterminer les teneurs en éléments nutritifs du substrat final (enrichi de déjections de ténébrions) afin d'identifier les meilleurs moyens de le valoriser sur place, à savoir quelles espèces de plantes intérieures et/ou extérieures s'adapteraient le mieux à ce fertilisant en fonction de leurs besoins spécifiques. Enfin, le déroulement des activités éducatives s'effectuera au cours des mois d'avril et de mai. En plus de miser sur la familiarisation comme stratégie permettant de surmonter les barrières perceptuelles à l'entomophagie, ces ateliers serviront de plateforme afin de récolter des données portant sur le comportement des gens face aux aliments inconnus (néophobie). Au courant de la première année de mon doctorat, j'ai élaboré des sondages et des guides d'entrevues semi-structurées ainsi que obtenu l'approbation éthique afin de procéder à leur distribution et à leur application. Le Biodôme me servira ainsi de plateforme où mettre en place ces techniques d'investigation, permettant ultérieurement l'analyse et la publication de données portant sur les habitudes alimentaires des différents groupes sociodémographiques. Celles-ci seront indispensables afin de cerner les stratégies les plus efficaces à être utilisées pour promouvoir l'acceptation culturelle des insectes comestibles chez la population montréalaise.

Milieu d'accueil et encadrement

Ce stage me permettra de développer des partenariats stratégiques avec des acteurs clés dans le secteur de l'agriculture urbaine et de la sensibilisation environnementale à Montréal. Le Biodôme représente un milieu exceptionnel, me donnant accès à un large éventail de ressources lesquelles me permettront d'obtenir de l'expertise dans des domaines qui dépassent mes propres champs de compétences. L'Insectarium, bénéficiant d'une étroite collaboration avec le Biodôme, pourrait s'avérer un atout essentiel au déploiement des activités de sensibilisation. L'implantation de ce réseau alimentaire alternatif jumelant élevage d'insectes et valorisation de résidus organiques constitue le premier volet de ma recherche-action, assurant ainsi le bon cheminement de mon cursus doctoral. Il me permettra, une fois le stage terminé, d'évaluer l'impact sur les barrières perceptuelles et économiques des activités de sensibilisation ainsi que du processus opérationnel mis en place. Le Biodôme bénéficiera également des retombées de ce stage en termes: 1) de positionnement stratégique dans un domaine de recherche de pointe ; 2) de mention dans les publications scientifiques qui en découleront ; 3) de potentiel de visibilité médiatique positive, notamment en association avec le développement durable, l'économie circulaire et la vie de quartier ; et 4) de rentabilité économique. Le projet CooleopTerre requiert des besoins mineurs en installations et en matériel et les risques potentiels qu'il comporte sont négligeables. Néanmoins, il pourrait permettre d'économiser sur les coûts d'achat d'aliments pour les animaux et de fertilisant pour les plantes. De plus, les ateliers éducatifs permettront de diversifier la gamme de services offerts par le Biodôme.

Sur le plan de l'encadrement, ce stage sera réalisé sous la supervision de Nathalie R. Le François, chercheure et conseillère scientifique pour le Biodôme depuis près de neuf ans. Sa connaissance du milieu d'accueil et son intérêt à intégrer les insectes dans les diètes d'animaux en captivité me seront d'une aide précieuse dans la réalisation des activités de ce stage. Stéphane Labelle, agent de conservation et de phytoprotection au Biodôme depuis plus de 28 ans, apportera une aide additionnelle et sera la personne ressource en ce qui a trait à la production de fertilisant pour les plantes. Louise Hénault-Éthier, chef des projets scientifiques à la Fondation David Suzuki et experte en élevage d'invertébrés, en gestion des déchets organiques ainsi qu'en vulgarisation scientifique, m'aidera à coordonner les activités d'élevage et à mettre en branle les ateliers éducatifs. Éric Lucas et Marc Fournier, respectivement directeur et technicien du laboratoire d'entomologie à l'UQAM, ont supervisé les tests d'alimentation de ténébrions au mycélium que j'y ai coordonné cet été. Ils demeureront des personnes ressources en cas de besoin. Marie-Hélène Deschamps et Grant Vandenberg, chercheurs en entotechnologies (c.-à-d. en gestion des déchets organiques par les insectes) à l'Université Laval, seront également partenaires affiliés à ce projet. Enfin, mon comité d'encadrement de recherche académique à l'Université Concordia est constitué de Satoshi Ikeda, spécialiste en agriculture urbaine durable, Jordan Lebel, expert en habitudes alimentaires, et Elizabeth Miller, dont l'expertise repose sur la communication scientifique sur l'écologie politique à travers les nouveaux médias.

Appendix E – Mitacs application (TriCycle)

Titre du projet:	EcoSix: L'élevage d'insectes comestibles en économie circulaire urbaine pour lutter contre le gaspillage alimentaire et les changements climatiques		
Nombre d'unités de stage:	15		
Mots-clés pour trouver les examinateurs:	Entotechnologies, entomophagie, surcyclage, économie circulaire, agriculture urbaine, gaspillage alimentaire, marketing alimentaire, fertilisation, automatisation, empreinte écologique		
Discipline:	Sciences de la vie		
Secteurs prioritaires du projet:	Durabilité et environnement	Biotechnologie	Agriculture et alimentation
	1	2	3

Plan de travail proposé par unité de stage (US):

		Années	Année 1			Année 2		
		Mois	1-4	5-8	9-12	1-4	5-8	9-12
Nom du stagiaire	Programme	US						
Didier Marquis	Doctorat	5	x	x	x	x	x	
A.	Maîtrise	4	x	x	x	x		
L.	Post-doctorat	6	x	x	x	x	x	x
Total d'unités de stage:		15						
Financement total du projet:		$200 000						

Ce projet créera-t-il de nouveaux liens de collaboration internationale? (x) Oui
Ce projet ne se déroulera pas à l'étranger mais il est à noter que nous sommes actuellement en attente d'obtention de financement en provenance de l'Union Européenne pour le consortium de recherche international Sustainable Insect Futures, lequel est basé à l'Université de Turku en Finlande et regroupe des chercheurs issus de plusieurs pays tels que l'Allemagne, le Danemark, la République tchèque, l'Australie, l'Inde et le Canada. L'objectif du consortium est de développer le marché des insectes comestibles en misant notamment sur l'identification d'espèces d'insectes compatibles avec les technologies d'élevage en économie circulaire, permettant la valorisation de sous-produits issus du secteur de la production et de la transformation alimentaire.

Titre du projet: EcoSix – L'élevage d'insectes comestibles en économie circulaire urbaine pour lutter contre le gaspillage alimentaire et les changements climatiques.

Résumé de la recherche (environ 200 mots):
Les insectes comestibles représentent une alternative durable à la viande conventionnelle. Les avantages se situent autant au niveau des valeurs nutritionnelles que de l'empreinte écologique. La diète omnivore des ténébrions meuniers peut permettre une saine gestion des résidus alimentaires. De plus, les déjections d'insectes ont des propriétés fertilisantes. Cependant, de fortes barrières psychologiques et économiques, dues notamment au manque d'expertise sur l'élevage d'insectes, freinent la progression de l'entomophagie (consommation d'insectes) au Canada.

Le projet EcoSix permettra de produire des insectes comestibles de grande qualité avec un impact environnemental minimal tout en générant un sous-produit bénéfique aux cultures végétales. Son objectif est de développer un procédé optimal pour l'élevage et la mise en marché de ténébrions en misant sur l'économie circulaire de proximité. Cela passera par l'optimisation de toutes les étapes du cycle de production: transport et traitement des intrants, confection des moulées, récolte, transformation, ensachage et distribution des insectes et de leurs déjections. De plus, des recherches seront menées afin d'enrichir la compréhension des enjeux et barrières à l'adoption et ce pour les divers acteurs principaux dans la chaîne de valeur. Des analyses nutritionnelles seront également réalisées sur les insectes et le fertilisant commercialisés. Enfin des analyses de performance environnementale permettront de mesurer clairement les bénéfices économiques et écologiques associés à l'élevage d'insectes en économie circulaire urbaine. Les recherches qui seront réalisées sur la lutte au gaspillage alimentaire permettront de démontrer la viabilité économique des procédés de valorisation circulaires, lesquels seront adaptables à divers contextes.

Renseignements généraux et revue de travaux antérieurs pertinents au projet (minimum 500 mots):
Des superficies totales des terres agricoles, environ 68% (3,3 milliards d'hectares) sont destinés à l'alimentation animale et 10% (500 000 hectares) sont utilisés pour produire des aliments destinés aux animaux d'élevage (Steinfeld et al., 2006). Au total, ce sont donc 78% des terres qui sont utilisés pour la production des animaux d'élevage. De plus, en 2014, 15,8 millions de tonnes de produits issus des pêcheries ont été transformés en farines et en huiles de poisson dont la majeure partie est utilisée pour nourrir la volaille, le bétail et les poissons d'élevage. La production mondiale de farines de poisson a atteint un sommet en 1994 et est en déclin depuis (FAO, 2018). Ses prix sont restés sous la barre des 1000 $US/tonne de 1987 à 2006 pour atteindre les 2000 $US/tonne en 2012 (Index Mundi, 2019), cette hausse étant principalement due à la surexploitation des stocks de poisson. La croissance rapide de l'industrie de l'aquaculture contribue fortement à l'augmentation de la demande. Ainsi, beaucoup d'efforts sont actuellement déployés afin de développer des protéines et des lipides plus durables en alternative aux farines de poisson conventionnelles (Craig, 2014).

Face à l'augmentation de la population mondiale ainsi qu'à la transition des diètes, il est estimé que la demande globale en protéines animales devrait doubler d'ici 2050 (Gouel & Guimbard, 2017). Son prix serait appelé à augmenter drastiquement, engendrant ainsi d'importants problèmes d'insécurité alimentaire (FAO, 2009). Afin de suffire à la demande alimentaire projetée, les pratiques d'offre doivent s'adapter à la réalité des ressources naturelles limitées. L'humanité consomme actuellement 1,7 fois les ressources disponibles sur la planète à chaque année.

Au Canada 58% de la nourriture est gaspillée et 79% de ces pertes se produisent avant même d'atteindre les consommateurs (Gooch et al., 2019). Au Québec, où l'on prévoit bannir l'enfouissement des matières organiques résiduelles d'ici 2020 (MDDEP, 2012), nos déchets sont responsables de 4,6% des émissions totales de GES (MDDELCC, 2019). Les principales solutions actuellement soutenues (le compostage et la biométhanisation) dégradent la valeur nutritionnelle des aliments et génèrent des sous-produits à faible valeur ajoutée. En parallèle, les animaux d'élevage sont directement responsables de 6,3% des émissions totales de GES dans la province (*ibid*.). De plus, la production des moulées animales conventionnelles pollue l'eau, appauvrit les sols et dégrade les écosystèmes.

La popularité des insectes comestibles grimpe en flèche depuis la parution en 2013 d'un rapport de l'Organisation des Nations unies pour l'alimentation et l'agriculture. Ce rapport affirmait que les insectes comestibles sont une alternative durable à la viande conventionnelle et représentent une solution viable aux problèmes d'insécurité alimentaire mondiale. À l'heure actuelle, plus de 2 111 espèces d'insectes sont reconnues comme étant comestibles pour l'humain (Jongema, 2017). Ils possèdent de nombreux avantages, notamment en ce qui à trait à leurs valeurs nutritionnelles, au taux de conversion alimentaire, à l'empreinte écologique de leur production et aux besoins matériels nécessaires à leur élevage. Par ailleurs, plusieurs de ces insectes possèdent une diète omnivore et qui peut s'avérer une solution intelligente pour permettre une saine gestion des résidus organiques urbains. Cela s'alignerait ainsi avec les objectifs gouvernementaux de bannir l'enfouissement des matières putrescibles dans les prochaines années.

Les insectes représentent une source de protéine durable tant pour la consommation humaine que animale, pouvant notamment entrer dans la composition des moulées pour la volaille et les poissons. Le marché des insectes pour l'alimentation humaine en Amérique du Nord était évalué à 55 millions US$ en 2017, une croissance de 43,5% du marché étant prévue pour 2024. Dans le monde, ce marché devrait atteindre 520 millions US$ en 2023 (Ahuja & Deb, 2018). En ce qui a trait à l'alimentation des animaux d'élevage, les besoins mondiaux en soja seront de 1,5 milliards de tonnes d'ici 2024. Il est anticipé que le marché des insectes pourrait remplacer 300 millions de tonnes de moulée animale. Au Québec, le marché de l'alimentation animale était évalué à 1,3 milliard de dollars en 2006 (Tremblay, 2009). Le prix moyen du soya en 2018 y avoisinait les 450$/tonne.

Pour faire face à la pression croissante de nos sociétés sur nos écosystèmes, il importe de revoir notre conception de la trame urbaine. Plutôt que d'y faire entrer des ressources extraites ou produites à l'extérieur de ses frontières et d'exporter les déchets issus des processus industriels se déroulant dans les frontières d'un quartier donné, il faut graduellement repenser nos villes à l'image des écosystèmes. Dans la nature, les déchets n'existent pas. Pour transformer la ville en écosystème fonctionnel, il est critique de favoriser les boucles d'économies circulaires par lesquelles les extrants d'une industrie peuvent servir d'intrants à la suivante. Les déjections d'insectes ont des propriétés fertilisantes pouvant permettre d'optimiser la croissance et de stimuler le système immunitaire des plantes. Ainsi, il est possible de ne générer aucun déchet au sein d'un élevage d'insectes optimisé.

Bien qu'il soit estimé que l'entomophagie (consommation d'insectes) est pratiquée par plus de deux milliards d'êtres humains dans le monde, de fortes barrières psychologiques empêchent son adoption généralisée. Ainsi, il est impératif de mettre l'emphase sur le développement de stratégies marketing efficaces pour la mise en marché des produits d'insectes. De plus, les coûts de production élevés, dû à leur forte dépendance en main d'œuvre, ainsi que le manque d'expertise pour l'élevage à moyenne et à grande échelle représentent d'autres freins à l'introduction des insectes sur le marché nord-américain. Il apparaît ainsi essentiel d'optimiser la production en passant notamment par la mécanisation et l'automatisation des procédés.

Le projet EcoSix permettra de produire des insectes comestibles de grande qualité avec un impact environnemental minimal tout en générant un sous-produit bénéfique aux cultures végétales. Il permettra de démontrer la viabilité économique d'un nouveau procédé pour la mise en valeur des résidus alimentaires locaux grâce aux insectes au sein d'un élevage urbain à moyenne échelle. Les recherches qui y seront réalisées sur la lutte au gaspillage alimentaire par les entotechnologies (élevage d'insectes à partir de résidus organiques) permettront de développer des procédés de valorisation circulaires adaptables à divers contextes.

Objectif général du projet de recherche divisé en sous-objectifs, activités, thèmes ou sous-projets, selon le cas:
L'objectif général du projet EcoSix est de développer un procédé optimal pour l'élevage et la mise en marché de ténébrions en misant sur l'économie circulaire de proximité.

Thème 1: Intrants utilisés pour l'alimentation des insectes (Session 1)
Sous-objectifs: L. (S1): Formulation de diètes optimales en fonction des différents stades de croissance
A. (S1): Développement d'un équipement de broyage et de déshydratation des intrants
Thème 2: Paramètres d'élevage et de récolte des insectes (Sessions 2 et 3)
Sous-objectifs: Didier (S1): Détermination des conditions environnementales favorables
A. (S2): Optimisation des procédés d'alimentation et d'élevage des insectes
A. (S3): Optimisation des techniques de récolte des insectes
Thème 3: Transformation des insectes (Sessions 1, 2 et 4)
Sous-objectifs: L. (S2): Développement d'un procédé de déshydratation des insectes
L. (S3): Analyse de salubrité bactériologique et des contaminants traces (insectes)
A. (S4): Optimisation des techniques de broyage d'insectes
Thème 4: Commercialisation des insectes (Sessions 3 et 4)
Sous-objectifs: Didier (S2): Identification des barrières à l'adoption
L. (S4): Optimisation des processus de conservation et d'emballage
Didier (S3): Identification des éléments clés pour l'élaboration d'une image de marque
Thème 5: Production de fertilisant organique (Sessions 4 et 5)
Sous-objectifs: L. (S5): Analyses agronomiques, de stabilité et de maturité du frass
Didier (S4): Valorisation des déjections d'insectes
Thème 6: Mise en place des procédés d'économie circulaires (Sessions 5 et 6)
Sous-objectifs: Didier (S5): Élaboration d'un modèle d'économie circulaire urbaine
L. (S6): Analyse du cycle de vie des insectes élevés en économie circulaire urbaine

Détails des stages de Didier Marquis par sous-projets:

Thème 2: Paramètres d'élevage et de récolte des insectes

1. Détermination des paramètres environnementaux optimaux pour l'élevage de ténébrions
   a. Identification des besoins physiologiques des ténébrions et de leur cycle de reproduction

   b. Élaboration d'un plan d'aménagement permettant de rentabiliser au maximum l'espace disponible pour l'élevage d'insectes

   c. Recherche et développement pour l'optimisation d'un système d'humidification, de ventilation et de climatisation à plus faible empreinte écologique

Thème 4: Commercialisation des insectes

2. Identification des barrières à l'adoption chez les consommateurs et les acteurs de l'industrie
Actuellement, les quelques études et travaux existants s'attardent principalement aux obstacles psychologiques chez les consommateurs (e.g., comment surmonter le dégoût que suscitent les insectes). La présente vise à tracer un portrait plus global et propre à la réalité québécoise. Ainsi, l'attention sera portée sur l'ensemble de la chaîne de valeur — des producteurs aux consommateurs en passant par les transformateurs — afin non seulement d'identifier les enjeux et barrières actuelles mais également de dégager des pistes de collaboration et d'innovation entre les divers acteurs de la chaîne de valeur.

a. Analyse des concurrents sur le marché canadien

b. Caractérisation des marchés locaux

c. Évaluation des préférences particulières des consommateurs pour les produits d'insectes

d. Réalisation d'études de cas à partir de produits d'insectes sur le marché

3. Identification des éléments clés à considérer pour l'élaboration d'une image de marque pour les produits d'insectes

a. Identification des éléments à prendre en considération dans le marketing des aliments nouveaux

b. Élaboration des profils de clients-cibles

c. Proposition d'une image de marque pour les produits d'insectes

Thème 5: Production de fertilisant organique

4. Valorisation des déjections d'insectes

a. Revue de la réglementation entourant la commercialisation de fertilisant au Canada

b. Évaluation des différents équipements et processus pour le tamisage des déjections

c. Évaluation des différents équipements pour capter la poussière des déjections

d. Expérience de croissance végétale

e. Rédaction d'un article scientifique sur les expériences de croissance réalisées précédemment

Thème 6: Mise en place des procédés d'économie circulaire

5. Gestion des intrants et des déchets de productions (fertilisant)

a. Identification des fournisseurs de résidus alimentaires

b. Élaboration d'une stratégie de distribution coopérative et de présence en commerce de détail

c. Optimisation des emballages permettant de préserver les propriétés physico-chimiques du fertilisant d'insectes

d. Identification des débouchés potentiels pour la valorisation du fertilisant

e. Rédaction d'un court article sur la conservation du fertilisant d'insectes

Avantages pour le stagiaire:
Ces stages s'insèrent parfaitement à l'intérieur de mon cheminement doctoral étant donné que ma méthodologie repose sur la recherche-action, soit l'application concrète de systèmes ayant pour but de provoquer des transformations sociales afin de répondre à des enjeux précis, tout en produisant des connaissances sur l'efficacité même de l'utilisation de ces procédés. Mes études interdisciplinaires - jumelant sociologie, marketing et sciences naturelles - pigent dans différents champs de pratiques et de compétences (habitudes alimentaires, comportements des consommateurs et élevage d'insectes comestibles) afin de proposer des réponses novatrices aux questions de recherche sur lesquelles je me penche. Cette approche me permet ainsi d'identifier des stratégies efficaces pour intégrer de façon durable la production et la consommation d'insectes comestibles dans les régions urbaines comme source locale de protéines animales. L'implantation d'un réseau alimentaire alternatif jumelant élevage d'insectes et valorisation de résidus organiques me permettra d'évaluer l'impact des stratégies marketing développées et du processus opérationnel mis en place sur les barrières perceptuelles et économiques à la production et à la consommation d'insectes comestibles au Canada.

Pertinence pour l'organisme partenaire et le Canada:
Les locaux de TriCycle permettront aux stagiaires d'avoir accès aux espaces de préparation des intrants, d'élevage d'insectes et de transformation des produits pour réaliser leurs expériences. Ils auront aussi accès aux espaces communs de la coopérative dans laquelle se situe l'entreprise TriCycle (bureau, salle de conférence, salle de lavage, cuisine, etc.). TriCycle offrira les ressources matérielles et financières nécessaires à la complétion des expériences (e.g. analyses de laboratoire, produits consommables, équipements de protection personnelle, larves de ténébrions, etc.). TriCycle sécurisera aussi l'accès aux équipements nécessaires à la préparation des intrants organiques et au conditionnement des insectes et des déjections grâce à ses liens étroits avec des fournisseurs ainsi que d'autres partenaires ayant déjà acquis des équipements similaires. Les tests des différents équipements pourront ainsi permettre d'identifier les meilleures techniques et procédés à intégrer dans les opérations de l'entreprise.

TriCycle bénéficiera du soutien des stagiaires et de leurs activités de recherche puisque les expérimentations permettront à l'entreprise de développer un procédé optimal pour l'élevage et la mise en marché de ténébrions en misant sur l'économie circulaire de proximité. Les stagiaires contribueront à l'optimisation de toutes les étapes du cycle de production: transport et traitement des intrants, confection des moulées, récolte, transformation, ensachage et distribution des insectes et de leurs déjections. TriCycle bénéficiera des revues de littérature scientifique, des analyses des pratiques industrielles d'autres acteurs du secteur et de la revue et l'évaluation des équipements industriels disponibles afin que soient choisis les meilleurs procédés possibles. Par ailleurs, les recherches menées afin d'enrichir la compréhension des enjeux et des barrières à l'adoption des insectes dans l'alimentation, et ce pour les divers acteurs principaux dans la chaîne de valeur, permettront à TriCycle de bien cibler sa clientèle pour adapter ses communications et stratégies de marketing, améliorant ainsi la pénétration des produits à base d'insectes à la fois sur les tablettes d'épiceries et sur les tables des consommateurs québécois. Les analyses nutritionnelles réalisées sur les insectes et le fertilisant commercialisés permettront à TriCycle de développer l'étiquetage de ses produits en fonction des exigences réglementaires. De plus, les analyses de performance environnementale permettront de mesurer clairement les bénéfices économiques et écologiques associés à l'élevage d'insectes en économie circulaire urbaine. Ceci permettra à l'entreprise de miser sur des messages de marketing fondés sur des évidences scientifiques directement appliquées aux processus utilisés en conditions réelles d'entreprise, et non seulement extrapolés à partir d'autres études scientifiques issues des quatre coins du monde. Les recherches qui seront réalisées sur la lutte au gaspillage alimentaire permettront de démontrer la viabilité économique des procédés de valorisation circulaires, lesquels seront adaptables à divers contextes. Les stages permettront à TriCycle de s'implanter solidement comme une plateforme de recherche et d'innovation dans le secteur des entotechnologies ainsi que d'acquérir l'expertise nécessaire à l'accompagnement d'autres éleveurs désireux de substituer des diètes céréalières pour les insectes par des diètes à base de résidus alimentaires disponibles dans leurs localités respectives.

À l'heure actuelle, au Canada, près de 60% des aliments sont gaspillés avant même d'atteindre le consommateur (Gooch et al., 2019). L'enfouissement de ces résidus organiques est responsable d'environ 5% des émissions de GES au Québec (MDDELCC, 2019). Malheureusement, le compostage et la biométhanisation, des méthodes actuellement privilégiées au Canada pour la valorisation des matières résiduelles organiques, sous-cyclent les aliments puisqu'ils dégradent les protéines, les lipides et les glucides en acides aminés, en éléments simples et en dioxyde de carbone. Si un compost se vend autour de 100$ la tonne, les insectes eux se vendent à plus de 10 000$ la tonne, donc une valeur ajoutée 100 fois plus grande. Le surcyclage à l'aide des insectes, appelé entotechnologies, est donc une opportunité intéressante d'ajouter de la valeur aux matières organiques. Il existe actuellement au Canada des entreprises fonctionnelles orientées vers la valorisation des insectes à l'aide des mouches soldat noires destinées à la nutrition animale, telles qu'Enterra en Colombie-Britannique et bientôt en Alberta ainsi qu'Entosystem au Québec. Une seule usine peut traiter jusqu'à 300 tonnes de matière organique par jour, des volumes comparables à ceux des grands sites de compostage. Il n'existe cependant pas d'entreprise orientée vers la valorisation des matières résiduelles issues du secteur agro-alimentaire à l'aide d'insectes destinés au marché de l'alimentation humaine. C'est le défi que relève TriCycle et c'est l'objectif que ces stages permettront d'atteindre. L'idée de valoriser des résidus organiques de grande qualité (avec un faible potentiel de contamination), dans des circuits courts (approvisionnements et ventes urbaines) et en offrant une vitrine technologique sur les processus d'économie circulaire est réellement novatrice. Ce type de développement est essentiel à la transition économique de notre société afin que notre approvisionnement alimentaire et notre gestion des matières résiduelles soient plus respectueux des limites de support de notre environnement, particulièrement dans un contexte de changements climatiques. Avec des données probantes colligées sous forme d'analyse de cycle de vie, ce stage permettra de confirmer le potentiel des bénéfices environnementaux issus du surcyclage local des matières organiques. Aucune autre étude de ce genre n'a auparavant été réalisée en contexte canadien, notamment car notre grille d'approvisionnement énergétique et notre climat diffèrent de ceux des autres analyses de cycle de vie américaines et européennes déjà publiées. Le dévoilement de ces résultats rendra accessible ces nouvelles données pour l'ensemble des canadiens.

Le soutien de Mitacs permettra à trois stagiaires cumulant déjà de nombreuses années d'expérience dans la gestion des matières organiques et l'entomophagie de poursuivre leurs recherches et d'appuyer le développement de cette entreprise durable d'agriculture urbaine. Ainsi, Mitacs appuiera la formation de personnel hautement qualifié dans un secteur en émergence pour l'industrie canadienne, pour lequel il n'existe pas encore de formation académique régulière. Par ailleurs, les connaissances développées au cours de ces stages serviront à l'élaboration de nombreux articles scientifiques, rapports et communications orales visant la diffusion des connaissances qui sont essentielles à l'émergence de ce secteur. La Fédération des producteurs d'insectes du Québec confirme d'ailleurs qu'il y a un grand besoin d'accompagnement en R&D pour les nombreux producteurs en démarrage à travers la province. Avec l'expertise développée durant ces stages, l'équipe de TriCycle sera bien positionnée pour aider d'autres entrepreneurs québécois à réduire l'empreinte environnementale de leurs élevages d'insectes comestibles.

Relation, le cas échéant, avec des projets Mitacs antérieurs ou d'autres projets Mitacs:
Didier a déjà complété trois unités de stage Accélération avec l'entreprise Alvéole dans le cadre de son doctorat avec l'objectif de: (1) implanter une ferme expérimentale d'élevage de grillons; (2) développer des prototypes de micro-fermes d'élevage d'insectes pour la vente aux particuliers, organismes et entreprises; et (3) élaborer des ateliers de sensibilisation et d'éducation à l'entomophagie et les entotechnologies afin de diversifier l'offre de services d'Alvéole sur le marché. La demande actuelle complète très bien le stage réalisé précédemment puisque l'expérience et les connaissances acquises seront mises à profit pour l'implantation d'une ferme d'élevage à plus grande échelle. Les procédés qui y seront développés permettront le dévoilement d'une vitrine technologique pour les autres producteurs d'insectes ainsi que la commercialisation de produits pour promouvoir l'émergence de la filière entomologique chez les consommateurs québécois.

Appendix F – Linking recycled water with edible insects' marketing challenges

Growing urban populations and industrial activities are leading to important drinking water shortages in many cities around the globe (Vörösmarty et al., 2010). Water and food consumption generate large amounts of waste. By 2050, the OECD estimates that almost half of the world population will be living in areas affected by serious water scarcity (OECD, 2012). Thanks to technological advancements, we are now able to upcycle wastewater originating from and intended for various uses. As is it the case with EI, recycled water consumption is considered a key solution to tackle and cope with climate change. It is available in many cities worldwide such as Singapore (NEWater) and San Diego (PureWater).

Due to psychological barriers, many people are also reluctant to drink purified wastewater for potable reuse. A parallel can be drawn on many issues linking edible insects (EI) with recycled water (RW):

1. Disgust is the most studied factor that prevent RW acceptability (Po et al., 2003);
2. Organoleptic factors: Visual aspect, taste, and smell can influence people's willingness to try RW;
3. Cost as compared to other viable options: RW is cheaper and requires less energy to produce than desalinated water (Awerbuch &Trommsdor, 2016). EI are also cheaper than other similar alternatives on the market, such as lab-grown meat (Axworthy, 2019);
4. Social norms and demographic factors: As it is the case with EI, RW acceptance rates vary importantly (ranging from 5% to 80%) amongst surveys led in different countries around the world, and even in different cities within them (Furlong et al., 2019);
5. Marketing: The terms used to describe RW (reused, recycled, repurified, reclaimed, effluent, or toilet to tap) affect largely people's acceptance (Rock et al., 2012). The name used to market EI must also be selected carefully (micro-livestock, alternative meat, mealworms/crickets, entomo proteins, etc.);
6. Knowledge: People that are aware that unplanned reuse is common in many public water supply systems are ten times more likely to be supportive of drinking RW (Rice et al., 2016). Insect fragments are also omnipresent in our everyday diets (Fantozzi, 2017). Emphasizing this fact could also prove effective in promoting entomophagy;
7. Information: Perceived health risk and damages to natural ecosystems linked to the use of unfamiliar technologies in purifying processes can influence public opinion towards RW (Dolnicar & Hurlimann, 2010). Following San Diego's intensive public relations campaign involving different media, people showing "strong opposition" to the project went from 45% in 2004 to 12% in 2009 (Furlong et al., 2019). Their campaign included tours of the demonstration facility and tasting activities, with over 14,000 people participating (*ibid.*). Neophobia towards EI is also responsible for generating perceived health risks. Also, the lack of understanding towards farming techniques and the threats they might represent for ecosystems (if farmed insects evade massively) have been shown to curb entomophagy acceptance. Better communicating the safe processes involved in RW & EI production as well as their different benefits could prove highly effective;
8. Baby steps: The gradual introduction of RW is necessary in order to gain social support (Dishman et al., 1989). A similar process must be carried out for EI to become accepted: first processed into familiar foods through gastronomy (invisible then visible), then whole

dehydrated (spiced to partly cover the flavor then natural to taste the insect), and finally cooked fresh (as meat would be consumed);

9. Endorsement: Part of their communication campaign, Singapore convened a panel of experts and had celebrities drink NEWater during public events, while they had the Prime Minister chant "Let's drink to the nation!" (Kaplan, 2016). Following the campaign, an independent survey showed that a 98% acceptance rate was achieved (Gallen et al., 2019). EI could also greatly benefit from such communication strategies;
10. Creating a social movement: Supporting public engagement and developing a sense of shared identity amongst community members is crucial in supporting RW acceptance (Ross et al., 2014). Public consultation focusing on non-technical aspects (e.g. environmental and social issues) are considered key aspects to ensure the success of RW projects (Harris-Lovett et al., 2015). A strong communication plan tackling different consumer touchpoints through various media could help create such a social movement to support EI consumption.

Of course, insects are very different from water as their consumption isn't yet part of a regular practice. However, a good understanding of issues that had to be addressed in order to promote public acceptance for RW might provide crucial insights for the instigation of biopolitical discussions surrounding both entomophagy and entotechnologies. The same way that RW allowed to trigger discussions about water pollution and sustainable management practices, EI can also serve as a medium to tackle the wicked problem of food waste. According to the Upcycled Food Association, "*60% of people want to buy more upcycled food, and that's because 95% of people care about food waste*" (Refab, 2020). Drinking RW is not so much of a choice for many inhabitants of many water scarce cities. If insects represent the best option to manage urban food waste, perhaps the anticipated drastic increase in meat prices will abort the acceptance debate and consumer's wallets will have the final word. But before we get there, many communication and marketing tactics can serve to gradually alleviate psychological and social barriers to entomophagy.

Appendix G – Marketing plan for an edible insect farming company

TriCycle: une ferme d'élevage de ténébrions qui opère en économie circulaire de proximité

Mission, vision, valeurs

Fondée en janvier 2019, Tricycle s'est donné comme mission de faire connaître le rôle des insectes comestibles en économie circulaire et de redonner vie aux aliments gaspillés en les réintroduisant dans la chaîne alimentaire locale. En s'inspirant du fonctionnement des écosystèmes, la vision de TriCycle est de voir naître un écosystème alimentaire responsable, durable et résilient, dans lesquels la nourriture gaspillée est revalorisée pour produire des aliments sains, locaux et nutritifs. Ses valeurs sont l'équité, la collaboration et le respect de l'environnement.

La gestion des matières résiduelles et l'agriculture sont responsables de 15,8% des émissions totales de gaz à effet de serre (GES) au Québec (respectivement 6,2% et 9,6%) (MDDELCC, 2019). À ces chapitres, les principaux facteurs déterminants sont le gaspillage alimentaire et la production de viande (fermentation entérique des bovins et gestion des fumiers). Considérant que 58% des aliments sont gaspillés au Canada, mais que la majorité (79%) de ces pertes se fait en amont des consommateurs (Gooch et al., 2019), il s'avère pertinent d'offrir une solution à ces enjeux dont la responsabilité ne repose pas uniquement sur les épaules de consommateurs. Le compostage et la biométhanisation, deux solutions technologiques actuellement priorisées au Québec, sous-cyclent les aliments puisqu'ils en dégradent les nutriments.

Les valeurs environnementales de TriCycle faisant partie des piliers de l'entreprise, les activités de recherche et de développement (R&D) sur la lutte au gaspillage alimentaire sont au cœur de ses activités. Ils visent principalement à développer des procédés de valorisation circulaires adaptables à divers contextes. La combinaison de l'entomophagie (consommation d'insectes comestibles) et des entotechnologies (procédés circulaires d'élevages d'insectes) offre une solution holistique et durable qui permet de réduire les impacts écologiques liés à la production et à la consommation de protéines animales conventionnelles (surexploitation des ressources halieutiques, émissions de GES, déforestation, eutrophisation des cours d'eau, perte de biodiversité, etc.) en plus de lutter contre le gaspillage alimentaire et de réduire l'empreinte carbone associée à la gestion des matières putrescibles.

Produits et services

Les procédés de valorisation entotechnologiques mis de l'avant par TriCycle permettent de réintroduire dans la chaîne alimentaire divers types de résidus propres et traçables issus des entreprises de production et de transformation alimentaire afin de produire des protéines animales durables à même l'écosystème urbain. Les résidus sont collectés auprès de partenaires situés à proximité de sa ferme, comprenant notamment du mycélium de champignon, de la drêche de brasserie, de la pulpe de jus, des écales de cacao et du son de blé. TriCycle mise sur un procédé de traitement de ces résidus organiques permettant de diminuer le temps et la main-d'œuvre nécessaires à leur prétraitement ainsi que leur conversion sous une forme hygiénique (hygiénisation thermique), assimilable par les insectes (réduction de la granulométrie) et conservable (dessiccation). Ces précédés entotechnologies améliorent ainsi la durabilité, la traçabilité et la salubrité des insectes comestibles. Les diètes sont développées dans l'objectif d'améliorer tant les paramètres de croissance et de reproduction des insectes que leur goût et leur qualité nutritionnelle.

En plus de produire des insectes comestibles, TriCycle valorise également les déjections de ses insectes afin de produire un riche fertilisant organique. Des études scientifiques récentes ont démontré que le frass de ténébrions, composé majoritairement de leurs déjections et de leurs exuvies (mues), peut aider les plantes à résister contre certains stress comme la sécheresse, les inondations et la salinité (Poveda et al., 2019). Les mues peuvent aussi contribuer à stimuler la production d'enzymes capables de dégrader la chitine, et donc aider les sols et les plantes à se parer contre les attaques d'insectes ravageurs ou de champignons pathogènes (Kombrink, 2011). Le frass offre une performance nutritionnelle comparable à un engrais de synthèse ou minéral avec une valeur nutritionnelle équivalente. En tant que fertilisant organique, il permet de supporter la biodiversité des sols et de préserver la qualité des cours d'eau puisqu'il entraîne moins de lessivage de phosphore et stimulerait davantage l'activité microbienne du sol. En outre, le frass est riche en oligoéléments et en matières organiques, des caractéristiques absentes des fertilisants de synthèse.

Du côté de son offre de services, TriCycle se positionne comme une entreprise experte dans la valorisation des matières organiques et offre plusieurs services de R&D, de consultation et d'accompagnement, notamment pour ceux et celles qui souhaitent développer ou optimiser leurs fermes d'élevage d'insectes. Ces services comprennent notamment les études de faisabilité, les prévisions budgétaires et de rendement, les devis de construction et d'opération, la distribution d'équipements spécialisés, la mise en service, la recherche de subventions, l'approvisionnement en moulées et en insectes reproducteurs, l'élaboration de protocoles de biosécurité et d'élevage, la mise au point de diètes issues de résidus alimentaires disponibles localement, les analyses de qualités nutritionnelles des larves et de qualités fertilisantes des déjections, les bioessais sur végétaux, l'accompagnement pour la mise en marché et la recherche de clients potentiels.

Avantages concurrentiels

Ayant comparé les caractéristiques des autres éleveurs approvisionnant le marché québécois, il a été possible de dresser une liste exhaustive des avantages concurrentiels de TriCycle:

- Une équipe forte et diversifiée d'experts cumulant plusieurs années d'expérience en élevage d'insectes et en gestion des matières organiques, jouissant d'un réseau diversifié dans le milieu de l'entomophagie;
- Un éventail de produits de ténébrions (larves fraîches, séchées, en poudre et nymphes) permettant d'offrir une plus grande liberté culinaire aux chefs afin de développer des recettes créatives;
- La plus faible empreinte environnementale de l'industrie québécoise de l'élevage d'insectes grâce à la valorisation des matières résiduelles dans les diètes d'insectes (plutôt que nourrir les insectes à partir de céréales et de moulées commerciales);
- Des coûts de production diminués grâce à l'utilisation de résidus organiques dans l'alimentation des insectes;
- Un approvisionnement local et distribution misant sur les marchés de proximité permettant aux partenaires de soutenir la durabilité écologique de leurs entreprises;
- L'optimisation du profil nutritionnel et du goût des larves à travers un solide programme de R&D pour soutenir la fidélisation de la clientèle;
- De nombreux partenariats avec des universités et des centres de recherche permettant une amélioration constante des diètes utilisées ainsi que des procédés d'élevage;
- Une expertise de pointe en lutte biologique et en contrôle bactérien assurant la grande qualité du plan de gestion des pestes et des pathogènes;

- Une affiliation au sein d'une coopérative de producteurs agricoles permettant de développer des processus de symbiose industrielle, de diviser les frais afférents à la production et à la transformation des insectes, ainsi que de jouir d'un réseau de distribution consolidé avec des partenaires locaux bien implantés.

Une matrice stratégique a également été réalisée sur la base d'une analyse SWOT (acronyme anglais pour Strengths, Weaknesses, Opportunities and Threats) qui détaille les forces, les faiblesses, les limites et les opportunités pour l'entreprise. Ce type d'analyse contribue à l'étude de la pertinence et de la cohérence des actions futures. L'analyse matricielle en deux dimensions est donc structurée pour mieux distinguer les points positifs (forces et opportunités) des éléments négatifs (faiblesses et limites) qui sont inhérents aux procédés (internes) ou qui relèvent du contexte (externe). Ce type d'analyse permet de réduire les incertitudes et d'affiner les stratégies futures pour le déploiement de l'entreprise.

Table 29. Analyse des forces, faiblesses, opportunités et contraintes de TriCycle

	Positif	Négatif
Interne	Forces • Production de ténébrions plus écologique que les élevages traditionnels utilisant des moulées de grain commerciales • Expertise et grande expérience des coéquipiers • Forte capacité à faire rayonner le projet grâce à un réseau étendu et une expertise en relations publiques/médias • Bonne connaissance de l'ouverture des consommateurs grâce à deux sondages rejoignant plus de 1500 québécois et canadiens en 2016 et 2018 • Bonne connaissance des tactiques et des stratégies de marketing des insectes • Bonne connaissance des enjeux réglementaires et politiques • Plan d'affaire équilibré entre R&D et production permettant d'aller chercher du financement diversifié • Coûts de location d'espace très faible • Possibilité de financement coopératif avec la Centrale Agricole (OSBL)	Faiblesses • Projet nécessitant beaucoup d'investissements en R&D (mais beaucoup de programmes de subvention disponibles) • Coûts de production élevés (mais il est possible de les réduire via l'automatisation des procédés et l'utilisation d'intrants gratuits) • Risques biologiques comme les bactéries pathogènes ou les maladies (mais nous misons sur un protocole strict de biosécurité)

Externe	Opportunités • Réel engouement mondial pour l'entomophagie découlant de la publication du rapport de la FAO en 2013 • Contexte local et international de lutte aux changements climatiques et au gaspillage alimentaire • Explosion du marché de l'entomophagie au Québec • Contexte réglementaire et politique favorable au Québec • Contexte municipal favorable: récente modification du zonage pour permettre les élevages d'insectes dans un périmètre dédié à l'agriculture urbaine au Marché Central • Géolocalisation optimale des locaux de TriCycle: près des grandes autoroutes (15 & 40) et des bassins de clients (contexte urbain) • Possibilité d'offrir nos formulations de moulées aux autres producteurs d'insectes	Contraintes • Appréhension des consommateurs face à l'entomophagie • Climat compétitif avec plusieurs producteurs récemment établis dans la province, et un des plus gros producteurs mondiaux établi en Ontario • Nécessité d'effectuer des analyses de salubrité coûteuses pour la consommation humaine ou une qualification très coûteuse pour faire autoriser nos ténébrions en nutrition animale (retombées potentielles intéressantes à long terme)

<u>Stratégie de commercialisation</u>

Pour la vente d'insectes, il est prévu de cibler différents marchés suivant les étapes de notre cheminement commercial. D'abord, la tendance dans le secteur entomophagique en est aux produits transformés. Les transformateurs de produits alimentaires à base d'insectes sont en prolifération au Québec. La demande est si forte que la grande majorité de ceux-ci doivent importer des insectes en provenance de l'extérieur de la province. Ils mettent en marché dans les épiceries et autres détaillants alimentaires des barres de céréales enrichies de protéines d'insectes (Uka Protéines, Naäk et Crickstart, dont les prix oscillent entre 2,50$ et 4,50$ par barre), des pâtes alimentaires (Mélio, vendues à plus de 7$ la boîte de 170g) ou des insectes entiers assaisonnés (La Mexicoise, vendus à 9,50$ pour 40g). Ce bassin fleurissant de transformateurs d'insectes comestibles s'approvisionne pour le moment en quasi-totalité chez le plus grand producteur d'insectes en Amérique du Nord, Entomo Farms. Plusieurs d'entre eux nous ont affirmé être à la recherche active de fournisseurs locaux. De plus, Wilder & Harrier ainsi que Hagen, deux compagnies locales qui produisent des gâteries pour chiens incorporant de la farine de grillon importée, se sont montrés intéressés par nos larves de ténébrions produites localement. Le secteur de la transformation alimentaire, tant pour l'alimentation humaine que animale, constitue ainsi un débouché sécuritaire pour nos produits étant donné les volumes requis. Mais les marges de profit sont nettement inférieures, les prix de vente en gros avoisinant actuellement les 45$ le kg, soit moins de la moitié des prix de vente au détail.

D'autre part, il existe un réel engouement pour les insectes comestibles chez plusieurs restaurateurs et traiteurs, reconnaissant le potentiel gastronomique de ces « nouveaux aliments ». Ceux-ci sont d'excellents agents d'influence du domaine culinaire, contribuant ainsi à consolider un bassin de clients potentiels. En effet, plusieurs d'entre eux nous ont confirmé leur intérêt pour nos produits (lettres d'intention signées). Afin d'augmenter davantage sa marge de profits, TriCycle souhaite mettre l'emphase sur la vente au détail, nécessitant des procédés de déshydratation et d'emballage ainsi qu'une architecture de marque et un réseau de distribution adéquats. À ce chapitre, les synergies que nous envisageons avec d'autres entreprises issues de l'agriculture urbaine et qui œuvrent à La Centrale Agricole pourraient faciliter le contact auprès de leurs clients actuels, tout en diminuant grandement les coûts de distribution. Les points de vente envisagés incluent les épiceries (produits tout en vrac et emballés), les marchés publics, les paniers de produits issus de l'agriculture locale ainsi que les plateformes de vente en ligne.

Stratégie de croissance
Avec sa première ferme modèle d'une superficie de 2 000 pi^2, TriCycle a développé des partenariats stratégiques afin de redonner vie à 79 tonnes de résidus végétaux collectés dans un rayon de 20 km de sa ferme pour produire 19 tonnes de fertilisant et près de 8 tonnes d'insectes sur une base annuelle. Les activités de production et de transformation de Tricycle se déroulent au sein d'une coopérative d'agriculture urbaine située en plein coeur de Montréal (La Centrale Agricole: Coopérative de producteurs, transformateurs et distributeurs agricoles urbains). Cette affiliation lui permet notamment de bénéficier d'infrastructures communes de réunion, de nettoyage, de stockage, de réfrigération, de transformation et éventuellement même de distribution alimentaire.

À l'été 2019, TriCycle s'est vu octroyer une subvention de 24 mois du Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec dans le but d'implanter une vitrine technologique portant sur les entotechnologies. Celle-ci vise à démontrer la viabilité économique et écologique d'un nouveau procédé pour la mise en valeur des résidus alimentaires locaux grâce aux insectes. Cette vitrine constitue un pôle rassembleur qui permet de forger des liens solides avec les autres entreprises du secteur agro-alimentaire via l'organisation d'une série de 12 ateliers rassemblant plus de 300 acteurs. Elle assure le transfert des connaissances scientifiques et techniques vers les divers acteurs de la filière, soient les entreprises génératrices de résidus agro-alimentaires, celles œuvrant dans la gestion des matières résiduelles organiques, les producteurs et les transformateurs d'insectes ainsi que les étudiants issus de ces domaines et de l'agriculture urbaine. Les activités de formation et de sensibilisation qui y sont offertes permettent de démocratiser tant les pratiques de production d'insectes que leur consommation, contribuant ainsi à développer le marché entomophagique. De plus, ces fonds serviront à acquérir de l'équipement spécialisé permettant le prétraitement des intrants organiques en vue de leur utilisation pour l'alimentation des insectes.

Au courant des deux prochaines années, les membres de TriCycle se concentreront sur l'optimisation des procédés de sa ferme modèle en ce qui a trait à l'alimentation des insectes et à la valorisation des résidus d'élevage, aux paramètres d'élevage, de récolte et de transformation des insectes ainsi qu'aux enjeux de commercialisation des produits. En mettant progressivement sur pied des procédés d'élevage et de transformation semi-automatisés, l'entreprise parviendra à limiter les opérations manuelles les plus chronophages, lesquelles représentent une part importante des coûts de production.

Dans trois ans, TriCycle procédera à l'expansion de sa ferme de production sur une superficie d'environ 3 000 pieds carrés. Cette ferme permettra de réaliser des économies d'échelle considérables puisque plusieurs étapes d'élevage pourront être robotisées. Avec cette hausse de productivité, le défi sera alors de se pencher sur le développement de nouveaux marchés. À ce sujet, les exuvies d'insectes contiennent une forte proportion de chitine, laquelle revêt un grand intérêt commercial, notamment pour les industries pharmaceutiques et des bioplastiques. TriCycle souhaiterait également diversifier sa gamme de produits d'insectes comestibles en élevant de nouvelles espèces.

Dans cinq ans, TriCycle souhaitera procéder à l'implantation de nouvelles fermes d'élevage d'insectes dans d'autres localités, contribuant ainsi au rayonnement des entotechnologies. En mettant sur pied de nouveaux réseaux d'économies circulaires de proximité, l'entreprise pourra ainsi multiplier son impact sur la diminution du gaspillage alimentaire, tout en augmentant l'offre d'insectes comestibles et de fertilisant d'insectes sur le marché canadien.

Analyses de marché

Environnement socio-culturel

Des sondages montrent qu'environ 95% des canadiens sont familiers avec la pratique de consommer des insectes (Hénault-Ethier et al., 2020). Plus de 60% des répondants avaient déjà goûté à des insectes et 92% d'entre eux seraient prêts à répéter l'expérience. De plus, 62% des gens n'ayant jamais goûté aux insectes seraient prêts à tenter l'expérience. Au total, 83% des consommateurs sondés en 2018 croient que les insectes représentent une source de protéine alternative intéressante afin de substituer leur consommation de viande. Dans la même année, moins de 8% des répondants étaient d'avis que les humains ne devraient pas manger plus d'insectes et moins de 7% s'opposaient à l'idée que plus d'animaux d'élevage devraient être nourris à partir d'insectes. Enfin, près de 80% des répondants considéraient l'entomophagie comme étant une pratique qui gagnera en importance au cours des prochaines années en Amérique du Nord.

Environnement compétitif

Le marché des insectes pour l'alimentation humaine en Amérique du Nord était évalué à 55 millions US$ en 2017, une croissance de 43,5% par an du marché étant prévue jusqu'en 2024 (Ahuja & Deb, 2018). Dans le monde, il était évalué que ce marché devait atteindre 520 millions US$ en 2023. Mais en 2019, Ahuja et Mamtani ont réévalué le marché mondial des insectes comestibles à plus 112 millions US$, anticipant une croissance de 47% par an jusqu'en 2026 – moment où il atteindrait 1,5 milliards US$.

Les insectes entiers font rapidement leur place sur les tablettes des épiceries. Ils sont notamment présents chez Provigo/Loblaw depuis plus d'un an, commercialisant sous leur marque maison de la poudre de grillon dont le prix de revient est de 133$/kg. Ceci a du même coup entraîné des ruptures de stock chez de nombreux transformateurs alimentaires s'approvisionnant en insectes. Des entretiens réalisés avec plusieurs de ces transformateurs ont révélé un fort intérêt de leur part à trouver un fournisseur fiable qui leur permettrait de s'approvisionner sur le marché local. D'après les études réalisées sur le marché québécois en mai 2020 (Tableau 1), le coût des ténébrions en format entier et déshydraté pour la nutrition humaine varie de 72,5$/kg à 295$/kg avec un prix moyen de 147$/kg. Les formats offerts varient de 20g (6$) à 2,27kg (203,50$). Sous forme de farine, les prix variant de 73$/kg à 170$/kg avec un prix moyen de 115$/kg. Les formats offerts varient de 34g (5$) à 2,27kg (220$).

Table 30. Formats et prix des insectes comestibles disponibles au Québec (mai 2020)

Compagnie	Statut	type	Format (g)	$ séchés	$/kg	$ poudre	$/kg

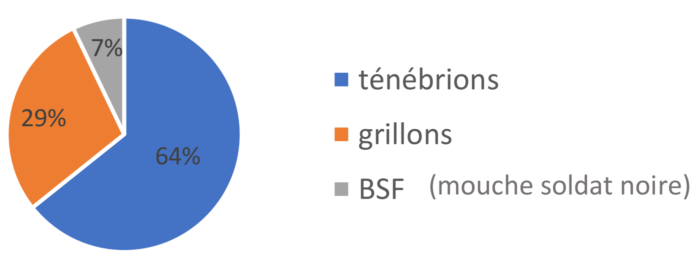
Entomo Farms	éleveur	grillons	56	$10,08	$180,00	nd	
			113	$16,50	$146,02	$12,38	$109,56
			454	$44,00	$96,92	$41,25	$90,86
			907	$82,50	$90,96	$79,75	$87,93
			2270	$203,50	$89,65	$192,50	$84,80
		ténébrions	56	$16,50	$294,64	nd	
			113	$18,98	$167,96	$19,25	$170,35
			454	$52,25	$115,09	$55,00	$121,15
			907	nd		$93,50	$103,09
			2270	nd		$220,00	$96,92
Vers chez soi	éleveur	ténébrions	100	$9,00	$90,00	nd	
			200	$16,00	$80,00	nd	
			400	$29,00	$72,50	nd	
Entomo DSP	éleveur	grillons	114	nd		$9,99	$87,63
			454	nd		$37,99	$83,68
			2270	nd		$164,99	$72,68
Les Grillonettes	éleveur	grillons	20	$6,00	$300,00	nd	
			100	nd		$14,00	$140,00
Entomoprotéine	éleveur	ténébrions	100	nd		$11,99	$119,90
Insectivores	éleveur	ténébrions	34	nd		$5,00	$147,06
Naak	transformateur	grillons	100	nd		$15,99	$159,90
			600	nd		$66,99	$111,65
Globe Protein	transformateur	grillons	114	nd		$13,99	$122,72
La Mexicoise	distributeur	grillons	40	$9,50	$237,50	nd	
			100	nd		$11,99	$119,90
			1000	$100,00	$100,00	nd	
Landish	distributeur	grillons	300	nd		$37,99	$126,63
			74	nd		$10,00	$135,14
Choix du président	distributeur	grillons	113	nd		$14,99	$132,65

En Chine les ténébrions sont disponibles à un prix plus faible grâce à une main d'œuvre moins chère. On y produit des ténébrions entiers dont les prix varient de 8 à 19 $/kg pour la nutrition humaine et de 5 à 14 $/kg pour la nutrition animale (excluant les taxes et les frais de livraison et de dédouanement). Cependant, les standards de salubrité peuvent être inférieurs aux standards nord-américains et il est difficile d'assurer la traçabilité des intrants utilisés.

Plusieurs producteurs d'insectes sont déjà établis ou en démarrage au Québec. Il existe d'ailleurs dans la province une Association des éleveurs et transformateurs d'insectes (AÉTIQ). Elle s'est donnée pour mission de rassembler et d'encadrer les producteurs et transformateurs d'insectes comestibles du Québec dans la mise en marché de leurs produits. Une rencontre des membres de cette association (anciennement fédération) en Janvier 2019 a rassemblé une soixantaine de personnes; il semble qu'il y aurait une trentaine d'éleveurs actifs ou en développement à l'échelle de la province, aucun se trouvant alors sur le territoire montréalais.

Le 30 mars 2020, une rencontre visant à rassembler les principaux acteurs de l'industrie des insectes comestibles a été organisée dans le cadre des activités de la Vitrine Entotechnologique de TriCycle, soutenue par le Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. Celle-ci vise à démontrer la viabilité économique et écologique d'un nouveau procédé pour la mise en valeur des résidus alimentaires locaux grâce aux insectes. Au total, 16 éleveurs et 13 transformateurs d'insectes ont participé à cette rencontre. De ces éleveurs, plus de la moitié ont démarré leurs activités en 2019 et neuf visent en premier lieu l'alimentation humaine. Plus de la moitié n'ont qu'un ou deux employés seulement et aucun n'en comptent plus de neuf. Leur production totale oscille entre 15 et 75 tonnes fraîches par année. Un seul répondant a affirmé élever des mouches soldat noires, destinées uniquement à l'alimentation animale. L'entreprise Entosystem en produirait cinq tonnes par jour dans son usine située à Sherbrooke. La quasi-totalité (94%) des 16 éleveurs d'insectes ayant participé au sondage concentrent leurs activités à l'échelle provinciale.

Figure 244. Types d'insectes élevés dans les fermes québécoises (sondage mars 2020)



Un des plus grands producteurs d'insectes au monde, qui approvisionne la quasi-totalité des fabricants de produits transformés à base d'insectes au Québec, se situe en Ontario. Fondée par trois frères en 2010, Entomo Farms a d'abord démarré dans le but d'approvisionner les animaleries pour l'alimentation des reptiles, prenant ensuite le tournant de l'alimentation humaine. Ils commercialisent des grillons entiers et en poudre, ainsi que des ténébrions en poudre (ces derniers sont régulièrement en rupture de stock). Le marché québécois est particulièrement vulnérable du fait que cette ferme représente pratiquement la seule source d'approvisionnement pour les gros volumes requis par les transformateurs. Dans les dernières années, des ruptures de stock liées à des problèmes de biosécurité au sein des élevages sont survenu.

<u>Plan de marketing</u>

Objectifs

Un plan de marketing permettra d'identifier adéquatement les étapes à franchir en lien avec la commercialisation des insectes comestibles, produits phares de TriCycle. La consommation humaine d'insectes comestibles ne date pas d'hier. Mais bien qu'il soit estimé que près de deux milliards d'êtres humains en consomment de façon traditionnelle, cette pratique est majoritairement restreinte à certaines communautés rurales originaires d'Asie, d'Afrique et d'Amérique du Sud (van Huis, 2016). Étant donné la transition globale des diètes vers le modèle occidental, caractérisé par la présence de produits hautement transformés et largement centré sur la protéine animale conventionnelle (Aiking & de Boer, 2018) l'aversion des occidentaux envers les insectes comestibles pourrait mener au déclin mondial de l'entomophagie.

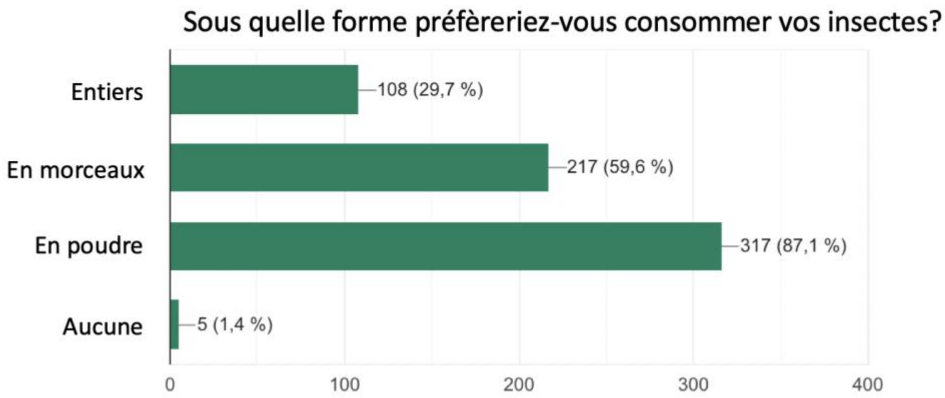
Plusieurs étapes seront à cibler, allant de la transformation à la vente des produits, en passant par le développement de stratégies marketing et d'une architecture de marque permettant de rendre les produits attrayants pour les consommateurs. Des défis particuliers relèvent du fait que les insectes comestibles sont à la fois nouveaux pour la majorité consommateurs et qu'ils évoquent davantage le dégoût que le désir. L'objectif du présent plan est d'en arriver à un tableau répertoriant les principaux enjeux à adresser et un plan adressant les cibles, les stratégies et les tactiques qui devront être implantés dans le but de surmonter ces défis de façon efficace et coordonnée.

Barrières à l'atteinte des objectifs
Ainsi, afin de favoriser l'acceptation des insectes comestibles en réduisant le pouvoir inhibiteur des représentations leur étant associées, il est stratégique de (1) favoriser l'identification de combinaisons gustatives intéressantes; (2) développer des recettes culturellement familières et (3) explorer de nouvelles avenues en ce qui a trait à la transformation des insectes pour en camoufler l'apparence. L'ensemble de ces stratégies devrait permettre d'identifier de façon plus stratégique la ou les catégories d'aliments auxquelles il serait préférable d'associer les insectes, nourrissant ainsi les discussions quant au positionnement de ces produits sur les tablettes des supermarchés.

La caractérisation des propriétés sensorielles des insectes et leur association à des marqueurs gustatifs connus permet de mieux identifier les potentielles combinaisons gustatives. Comme cela a déjà été le cas par le passé avec le poisson cru et les sushis, la combinaison d'un nouvel aliment avec des ingrédients familiers peut permettre d'augmenter la probabilité d'essai des consommateurs en améliorant leurs attentes sensorielles initiales. De plus, les préparations familières peuvent aussi inciter les intentions d'essai et même d'achat des consommateurs envers ces nouveaux produits alimentaires puisque ces recettes contribuent à les normaliser (*ibid.*). Enfin, tel que discuté précédemment, la transformation des insectes sous forme de poudre ou de morceaux est une avenue simple qui permet de surmonter le sentiment de dégoût et ainsi inciter les gens à tenter l'expérience et à apprivoiser progressivement le goût des insectes.

Effectivement, notre étude de marché réalisée en 2018 nous démontre que la majorité des gens préfèrent consommer des insectes sous une forme non visible, soit en poudre ou en morceaux. Bien que les consommateurs sondés aient affirmé avoir une légère préférence pour les grillons face aux ténébrions lorsque ces insectes sont disponibles sous forme visible (entiers), cette préférence s'estompe lorsqu'il s'agit d'insectes réduits en morceaux ou en poudre. Au courant des dernières années, plusieurs entreprises commercialisant des produits à base d'insectes (barres énergétiques, pâtes, pains, biscuits, etc.) ont ainsi opté pour la réduction des insectes sous forme de poudre afin de surmonter le dégoût face aux insectes. Bien que cela représente une bonne façon d'expérimenter avec la pratique de l'entomophagie, cette stratégie permet difficilement aux consommateurs d'intégrer cette nouvelle habitude à leur corpus alimentaire sur une base régulière. De plus, ces aliments sont souvent hautement transformés, ce qui diminue les bénéfices sur la santé associés à leur consommation.

Figure 25. Préférence par rapport à la forme des insectes (source: Marquis et al. 2018)



Stratégie de segmentation

Afin de maximiser l'efficacité des stratégies utilisées pour promouvoir l'acceptabilité des insectes comestibles, il est essentiel de différencier les groupes types de consommateurs et d'identifier ce qui motive leurs choix respectifs. Tous n'ont pas le même degré ni le même type d'intérêt envers les aliments qu'ils consomment. Les choix alimentaires sont dictés par divers moteurs, lesquels prennent une importance plus ou moins grande en fonction des caractéristiques individuelles. Il est possible de distinguer les moteurs traditionnels (propriétés organoleptiques, commodité et prix) des facteurs émergents (santé et bien-être et éthique environnementale, sociale et animale), lesquels ne pèsent pas le même poids dans la balance décisionnelle des individus. Des approches de marketing distinctes et complémentaires devront ainsi être élaborées. La segmentation des profils de clients cibles et l'élaboration de "personas" permet de mieux guider l'élaboration des stratégies de marketing visant à générer un essai initial des produits à base d'insectes et, surtout, d'inciter à la consommation pour générer un rachat rapide et soutenu dans le temps.

Les consommateurs innovateurs qui s'intéressent aux insectes comestibles ont précédemment été décrits comme étant des jeunes hommes néophiles, concernés par les enjeux environnementaux, se traduisant en une forte conscience alimentaire (Verbeke, 2015). Ainsi, ce descriptif rejoint deux grandes catégories de consommateurs: ceux davantage influencés par la recherche de nouvelles saveurs (ou TOC, pour *taste-oriented consumers*) et ceux qui sont plutôt consciencieux de l'impact de leurs choix (ou ROC, pour *reflection-oriented consumers*) (de Boer et al., 2007). Les TOC ont tendance à être aventuriers et impulsifs et attachent habituellement peu d'importance au prix des aliments et à la facilité de les apprêter. Bien qu'un des facteurs limitatifs au marketing des insectes demeure leur prix élevé, plusieurs consommateurs de ce type sont prêts à payer une prime pour les produits qui répondent à leur soif de découverte. Les ROC sont quant à eux en général des gens plutôt éduqués, disposant d'une grande conscience alimentaire et attirés par les produits naturels, santé, écologiques et/ou éthiques. Il peut sembler paradoxal d'avoir ces deux types de consommateurs en tant qu'utilisateurs *innovateurs*, mais c'est ce qui fait des insectes comestibles un aliment aussi intéressant: ils sont à la fois méconnus, goûteux, sains et durables. Ces caractéristiques peuvent représenter un fort avantage et doivent ainsi être exploitées judicieusement.

D’autre part, les préférences et les aversions alimentaires tendent à rester relativement stables jusqu’à l’âge adulte (Rigal, 2010). Étant donné que les habitudes alimentaires des jeunes sont moins ancrées, ceux-ci sont souvent moins réticents face aux nouveaux aliments (Tuorila et al., 2001). Des stratégies efficaces conçues pour former de futurs entomophages pourraient s'avérer particulièrement prometteuses, d'autant plus que ces jeunes ont un fort pouvoir d’influence vis-à-vis de leurs pairs et des membres de leur ménage. Les jeunes ont une influence énorme et rapide, étant responsables de plus de 50% des nouveaux produits qui entrent dans leur maison (Brée, 2012). Lorsque l’expérience de consommation d’un nouvel aliment est positive, elle a tendance à être souvent reproduite. Les jeunes devraient ainsi être mis à profit dans les efforts visant à accélérer l'adoption généralisée des insectes comestibles. Ils pourraient permettre d’altérer de façon plus rapide les représentations mentales de la société afin que les insectes soient ainsi perçus comme des aliments à part entière.

Mise en marché

a. Commodité

Un facteur central auquel les consommateurs accordent une importance croissante est la commodité des produits, soit le temps et l’énergie (mentale et physique) qui doivent être consacrés de la décision d’achat, à l’achat, la préparation, la consommation et au débarrassage des aliments. Ainsi, des arguments décisionnels clairs, une disponibilité accrue dans les restaurants et les épiceries, un positionnement stratégique sur les étalages des détaillants ainsi que des idées recettes qui permettent de contourner les barrières psychologiques à la consommation sont toutes des stratégies qui doivent être mises de l’avant afin d’augmenter la commodité des produits d’insectes. De plus, le prix des produits influence leur commodité perçue puisque celui-ci est intimement lié à la dépense d’énergie nécessaire à l’obtention d’une rémunération financière par le consommateur, lequel choisir par la suite de la dépenser stratégiquement afin de rentabiliser le fruit de son travail. Bien que nos sondages démontrent que le prix élevé des insectes ne représente pas un facteur important freinant leur expérimentation par le consommateur, il représente certainement une barrière à leur consommation régulière. La popularisation anticipée des insectes comestibles au courant des prochaines années contribuera à abaisser progressivement leur coût sur le marché puisqu’elle entraînera inévitablement une hausse des investissements permettant la réalisation d’économies d’échelle.

Promouvoir la portabilité et la commodité des collations transformées à base d’insectes pourrait s’avérer très efficace à l’ère où les collations sur le pouce gagnent grandement en popularité. Les dernières années ont vu la prolifération de nombreuses entreprises proposant des collations à base d'insectes. Le fait de commercialiser les insectes de cette manière constituerait un moyen prometteur d'accroître l'acceptation des consommateurs (Gmuer et al., 2016). Afin que de tels produits concordent avec les bénéfices mis de l’avant sur la santé des consommateurs, il faudra éviter de trop les transformer, en réduisant au minimum la liste d’ingrédients, particulièrement le sucre, le sel et les gras.

Cependant, il y a là une dichotomie puisque les insectes sont souvent représentés comme une alternative durable à la viande conventionnelle, pouvant entraîner une certaine confusion chez les consommateurs. Mais si les insectes sont ainsi positionnés, ils doivent être en mesure de compétitionner au plan économique avec les autres produits d’origine animale, ce qui n’est pas le cas à l’heure actuelle. Ainsi, à court terme, il semblerait plus stratégique de classifier les insectes avec les autres aliments optionnels, tels que les collations et suppléments. Cette catégorie peut permettre d'augmenter les opportunités d'essai à court terme et ainsi contribuer à la popularisation des produits d'insectes, entraînant une hausse de la demande et une diminution probable des prix.

b. Emballage

Le matériau, la texture et l'aspect de l'emballage dicte son attrait visuel ainsi que sa sensation tactile et sonore, lesquels aspects influencent en retour la première impression du consommateur. Par exemple, la transparence de l'emballage engendre un effet de saillance qui encouragerait les consommateurs à acheter des aliments santé (Dai et al., 2020). Cet effet est cependant largement modéré par la caractéristique des aliments contenus dans l'emballage (Deng & Srinivasan, 2013). Étant donné que les insectes évoquent largement le dégoût, les emballages transparents sont ainsi à proscrire.

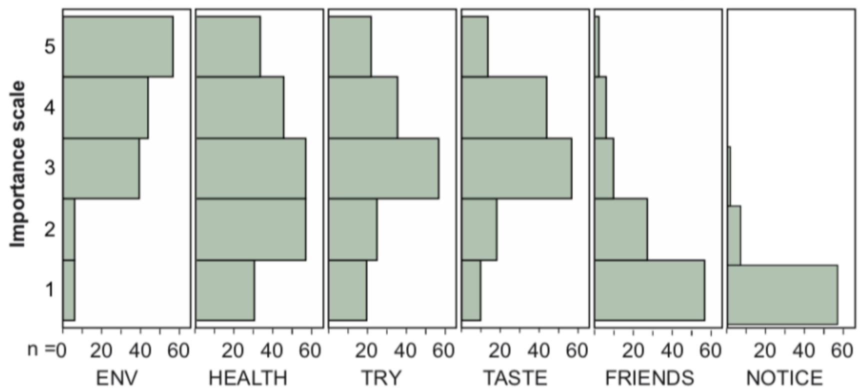
À ces défis s'ajoutent une contrainte importante: l'emballage des insectes doit permettre la préservation de leurs propriétés organoleptiques et de leur salubrité. Ainsi, il est essentiel de comparer adéquatement les bénéfices et inconvénients associés aux différents modes de conservation (congélation, blanchiment, déshydratation à chaud, déshydratation à froid, rôtisserie) utilisés pour tous les aliments sensibles à l'oxydation des lipides, tels que les insectes. L'objectif principal est de préserver la digestibilité des macro-nutriments, soient des protéines et des acides gras polyinsaturés, et de prévenir la dégradation des paramètres organoleptiques des insectes. Le choix des matériaux (plastiques, verre, métal, bioplastiques) et des procédés d'emballages (sous-vide, autoclave, sertissage) est ainsi à prendre en considération car il dictera la perméabilité à l'oxygène et la transparence à la lumière.

De plus, étant donné les contraintes d'espace liées au contexte urbain ainsi que les valeurs d'entreprise propres à TriCycle, il est nécessaire de considérer la facilité de stockage et de manutention des emballages ainsi que leur potentiel de réutilisation ou de recyclage, tout en évitant le suremballage. Ainsi, une sélection judicieuse d'emballages respectueux de l'environnement pourrait rendre le produit plus cohérent avec les valeurs d'entreprise. Certains emballages seraient à éviter, tels que le polystyrène expansé, les emballages en plastique multicouche ou les emballages conçus à partir de matériaux mixtes. TriCycle a déjà entamé des discussions avec des producteurs d'emballages locaux (Cascades) afin de faire développer un produit répondant à la fois aux critères écologiques, de préservation de la fraîcheur et de la salubrité des insectes.

c. Noms, slogans et image de marque

Les études de marché réalisées entre 2016 et 2020 par les membres de TriCycle révèlent que le principal facteur de motivation incitant les consommateurs québécois à s'intéresser aux insectes comestibles est sans contredit la préservation de l'environnement (Hénault-Ethier et al., 2020). Ainsi, en misant sur l'économie circulaire pour produire ses insectes à l'échelle locale, TriCycle parvient simultanément à réduire ses coûts d'élevage, à produisant des insectes plus nutritifs et à répondre aux préoccupations réelles de sa clientèle en offrant une protéine alternative plus respectueuse de l'environnement que les autres élevages d'insectes destinés à l'alimentation humaine (nourris à partir de moulées issues majoritairement de l'agriculture non durable). Cependant, des stratégies de communication doivent être élaborées afin que ces arguments puissent parvenir à influencer le comportement des consommateurs.

Figure 26. Importance accordée à divers facteurs motivant l'entomophagie chez les consommateurs québécois (2016)



Environnement (ENV), Santé (HEALTH), Curiosité (TRY), pour connaître le goût (TASTE), parce que des amis l'ont essayé (FRIENDS) ou pour se faire remarquer dans son réseau (NOTICE). L'échelle varie de 1 (pas du tout important) à 5 (très important).

Le nom d'entreprise TriCycle fait lui-même référence au processus d'élevage en économie circulaire. Celui-ci peut entraîner une certaine confusion chez les consommateurs puisqu'il est peu révélateur des produits commercialisés par l'entreprise. Ainsi, une marque appropriée doit être élaborée pour les insectes de TriCycle, en évitant toutefois d'évoquer l'insecte de façon trop directe. De plus, les stimuli informationnels et les labels nutritionnels et environnementaux peuvent avoir un impact important sur les réactions affectives et cognitives des consommateurs (Dufeu et al., 2014; Pantin-Sohier & Miltgen, 2012).

Toutefois, il est essentiel de prendre en considération les deux principaux types de consommateurs potentiels de produits d'insectes identifiés précédemment (TOC et ROC) ainsi que les importantes barrières à la consommation (néophobie). Comme les slogans mixtes ont prouvé leur inefficacité à convaincre les consommateurs (Fenko et al., 2015), différentes gammes de produits, avec des revendications distinctes, pourraient être commercialisées simultanément en ciblant différents groupes de consommateurs qui ne réagissent pas de la même manière aux messages cognitifs et affectifs. Ainsi, les insectes entiers séchés pourraient viser principalement un marché de consommateurs plus néophiles (TOC) tandis qu'il pourrait être stratégique que les produits d'insectes en poudre soient davantage orientés envers les ROC.

Les TOC sont plus enclins à prendre des décisions d'achat spontanées, lesquelles ne sont souvent pas rationnelles mais plutôt basées sur des facteurs émotionnels. Le nom et les courts slogans choisis pour les produits d'insectes devraient ainsi évoquer l'exotisme. Mettre l'emphase sur le goût unique des insectes tout en fournissant des idées de recettes pour les cuisiner pourrait aussi encourager ces consommateurs à tenter l'expérience, que ce soit par défi personnel ou pour impressionner leurs proches.

Afin de rejoindre les consommateurs plus consciencieux (ROC), lesquels sont plus susceptibles de passer du temps à analyser les informations contenues sur l'emballage, les messages devraient mettre l'emphase sur les divers bénéfices associés à la consommation d'insectes. Les ROC répondent mieux aux arguments marketing renforçant les associations entre la consommation d'insectes et la durabilité environnementale et sociale ainsi que la santé humaine et l'éthique animale (Bertolotti et al., 2016). Des bénéfices écologiques clairs et justes devront être élaborés et schématisés (p. ex. utilisation de terres, de moulée, d'eau et d'énergie versus la viande conventionnelle) afin de soutenir un « *nudging* » (Purnhagen et al., 2016) efficace.

Ainsi, certains arguments devraient mettre de l'avant le potentiel des insectes à améliorer la sécurité alimentaire locale (élevage urbain ou domestique) et globale (production de masse dans les pays en situation alimentaire précaire). Des slogans mettant l'emphase sur l'aspect naturel du produit, sans additifs artificiels, pourraient s'avérer fort efficaces. Afin de rejoindre les préoccupations des végétariens non véganes qui recherchent des sources alternatives de protéines et de micronutriments, une gamme de produits d'insectes positionnés comme substitut de viande durable et nutritif pourrait s'avérer efficace envers ces consommateurs, souvent prêts à payer une prime additionnelle pour ce type de produits. À ce sujet, une meilleure transparence face aux habitudes alimentaires et du cycle de vie des insectes comestibles pourrait permettre de rejoindre les valeurs de ces consommateurs.

Comme le consommateur est bombardé de produits et de publicités revendiquant une panoplie de motifs des plus simplistes aux plus farfelus pour attirer son attention mais qu'il ne dispose souvent que de quelques secondes pour faire son choix, l'identité visuelle doit être attentivement réfléchie, incluant une typographie et une palette de couleurs permettant de soutenir adéquatement les valeurs de l'entreprise. Ainsi, selon la théorie du comportement décisionnel, les représentations visuelles associées à la marque constituent des raccourcis cognitifs exploités par le consommateur afin de simplifier sa prise de décision (Gallen, 2005). Les attributs structurels, graphiques et textuels de l'emballage permettant au consommateur de créer des inférences sur le produit et la marque (Lancelot Miltgen et al., 2016).

L'élaboration d'une image et d'une identité de marque fortes et efficaces pour les produits d'insectes doit permettre de tirer profit des stratégies identifiées précédemment dans le but d'influencer et de surmonter les barrières psychologiques à la consommation des différents profils de clients-cibles. Cela permettra également de différencier les produits face à nos concurrents au niveau des divers points de contact ("*touchpoints*") établis avec la clientèle, lesquels seront d'ailleurs à identifier via l'élaboration d'un plan de communication détaillé.

Tactique de support à la marque

a. Sensibilisation et éducation

Afin de favoriser l'essor du marché entomophagique au Québec, Tricycle veille à l'élaboration d'outils de communication et d'éducation visant à surmonter les barrières perceptuelles à la consommation d'insectes, en mettant notamment l'emphase sur la réduction du danger perçu et les divers bénéfices liés à leur consommation. Afin de se familiariser avec les insectes, des ateliers seront aussi donnés sur les méthodes d'élevages de ténébrions. Ceux-ci permettront d'en apprendre davantage sur la biologie des insectes et leurs besoins spécifiques. De plus, de plus en plus de gens désirent élever des insectes pour leur consommation personnelle ou pour en tirer un revenu. La situation récente liée à la COVID-19 semble générer un engouement soutenu pour la production alimentaire domestique. Ainsi, des kits d'élevage domestiques accompagnés de d'un pamphlet d'instructions simple sont en train d'être mis sur pied par les membres de TriCycle. Les arguments de marketing développés pour faire la promotion de ces fermettes de microbétail mettront de l'avant les bénéfices liés à l'autonomie alimentaire.

a. Gastronomie

Les influenceurs gastronomiques représentent des collaborateurs inévitables pour la promotion des insectes comestibles. Au courant de la dernière année, un partenariat avec l'Institut du Tourisme et de l'Hôtellerie du Québec a été mis sur pied permettant d'explorer davantage le potentiel gastronomique des insectes. À présent, des dégustations avec les chefs apprentis ont permis de caractériser les propriétés organoleptiques (couleur, apparence, goût, texture, odeur) des ténébrions déshydratés à différentes températures afin d'identifier le procédé de transformation le plus adéquat. Un second exercice a permis de comparer le profil sensoriel de la larve de ténébrion déshydratée au micro-ondes ou au déshydrateur avec celui de la nymphe de ténébrion, du grillon, de la sauterelle aromatisée à la lime et d'un mélange d'insectes sucrés.

Au courant des prochains mois, TriCycle souhaitera consolider son partenariat avec l'Institut du Tourisme et de l'Hôtellerie du Québec afin d'explorer davantage les combinaisons gustatives, les recettes familières et la transformation des insectes comestibles. Cela permettra à TriCycle de mettre en ligne des idées de recettes et d'offrir des ateliers de cuisine permettant d'apprendre aux gens à apprêter les insectes pour les rendre appétissants, consolidant du même coup le bassin de consommateurs actuels. Ainsi, les insectes commercialisés par TriCycle doivent être disponibles sous forme entière afin de tirer pleinement profit des opportunités gastronomiques (texture) et de donner une plus grande liberté culinaire aux restaurateurs, traiteurs et consommateurs.

b. Endossement

L'endossement par une personnalité connue et de confiance permet à la fois d'attirer l'attention des consommateurs ainsi que de soutenir un meilleur traitement de l'information et une mémorisation accrue des messages véhiculés (Keel & Nataraajan, 2012). Les membres de Tricycle ont participé en juin 2018 à la webdiffusion d'un épisode spécial de Bob le Chef où des recettes à base d'insectes ont été élaborées en direct. Cet épisode, d'une durée de trois heures et demie, a été suivi en direct par 823 internautes en plus d'atteindre 900 vues en rediffusion sur Youtube. Les publications Facebook par l'équipe de Bob le Chef en lien avec cet épisode (partage de photos et lien vers les recettes) ont atteint 6,000 personnes et les articles publiés (recettes et blogue) ont été consultés à plus de 2,400 reprises. Malheureusement, à ce moment les produits d'insectes de TriCycle n'étaient pas encore disponibles. Au courant des prochains mois, TriCycle souhaite ainsi répéter l'expérience en mettant de l'avant des recettes préparées avec des chefs connus et présentées sous forme de capsules vidéo et d'articles web.

c. Valeurs écologiques

Afin de soutenir ses valeurs écologiques, TriCycle pourrait chercher à obtenir certaines certifications, telles que « *B Corp.* », laquelle comporte des responsabilités légales et est la preuve du sérieux des préoccupations de l'entreprise. Par ailleurs, il a été choisi que le site web de TriCycle soit hébergé sur le domaine « *.eco* » qui regroupe une communauté d'entreprises et d'OSBL à caractère environnemental. L'organisation de ce domaine s'est elle-même dotée d'une forte politique environnementale, cherchant à réduire sa consommation énergétique ainsi que ses émissions afin que l'hébergement web ait la plus faible empreinte environnementale possible. Pour accroître son impact, TriCycle s'engage également à remettre 1% de ses profits à la Fondation David Suzuki. Créé en 1990, cet organisme pancanadien sans but lucratif a son siège social à Vancouver et compte des bureaux à Montréal et à Toronto. La Fondation s'appuie sur des recherches scientifiques et mise sur la sensibilisation ainsi que l'analyse de politiques d'intérêt public pour défendre la conservation et la protection de l’environnement afin d’aider à dessiner un avenir plus vert pour le Canada.

Table 31. Synthèse des enjeux, objectifs, stratégies et tactiques

Enjeux	Objectifs	Stratégies	Tactiques
A. Barrières psychologiques	1. Augmentation de l'attrait sensoriel	Modification des propriétés organoleptiques	Transformation des insectes pour en modifier l'apparence (en poudre et broyés)
		Développement d'emballages attrayants permettant de préserver les macronutriments	Emballages opaques, hermétiques et recyclables
	2. Modification des représentations mentales	Sensibilisation à la biodiversité des insectes (comestibles et non-comestibles)	Exploitation du cosmopolitisme gastronomique québécois
		Transparence face aux habitudes alimentaires et au cycle de vie des insectes	Schémas illustrant les cycles de production; Vidéos montrant les élevages d'insectes; Ateliers portant sur les méthodes d'élevage; Kits d'élevage domestique
	3. Stimulation des intentions d'essai	Cibler les jeunes (pouvoir d'influence)	Activités de familiarisation dans les écoles
		Architecture de marque et guides d'identité visuelle en adéquation avec les valeurs d'entreprise	Attributs structurels, graphiques et textuels permettant de créer des inférences sur le produit et la marque
	4. Meilleure connaissance de l'aliment	Gastronomie: emphase sur la palatabilité	Caractérisation des propriétés sensorielles; Association à des marqueurs gustatifs connus; Identification de combinaisons gustatives; Développement de recettes culturellement familières

Enjeux	Objectifs	Stratégies	Tactiques
B. Popularisation d'une innovation de discontinuité	1. Compréhension simplifiée des bénéfices	Outils de communication et d'éducation	Endossement par une personnalité connue (mémorisation accrue des messages); Endossement par un expert (crédibilité accrue); Marques et slogans mettant de l'avant les procédés d'économie circulaire locaux
		Plan de communication détaillé	Évaluation des points de contact avec la clientèle; Noms des produits et slogans évocateurs; Revendications claires et adaptées aux personas
	2. Simplification d'utilisation	Développer des idées de recettes	Partenariat avec des restaurateurs, traiteurs et instituts
	3. Augmentation des occasions d'essai	Présence dans les restaurants et épiceries	Démarchage auprès de commerces stratégiques; Dégustations
	4. Observabilité des bénéfices	Quantification des bénéfices	Analyses nutritionnelles complètes; Représentation imagée des bénéfices sociaux
		Endossement par des organismes reconnus	Certification B Corp., Aliment du Québec & Écocert; Hébergement web *.eco;* 1% des profits à la Fondation David Suzuki (indication sur l'emballage)
C. Commodité	1. Réduction du prix des produits	Diminution des coûts de production et de distribution	Valorisation de résidus organiques; Automatisation des procédés; Distribution coopérative
	2. Portabilité accrue	Commercialisation de collations et suppléments	Partenariat avec des transformateurs alimentaires
	3. Amélioration de la pénétration des produits à base d'insectes	Présence en commerce de détail	Études de cas: entretiens avec des dirigeants d'entreprises permettant d'explorer leurs enjeux et les décisions qu'ils ont prises et les réponses et comportements des consommateurs qui en ont découlé
	4. Facilité d'achat	Vente directe au consommateur	Plateforme de vente en ligne

Enjeux	Objectifs	Stratégies	Tactiques
D. Mise en marché	1. Identification des segments de marché	Caractérisation des marchés locaux	Études de marché recensant les entreprises offrant des produits d'insectes sur le marché québécois; Inventaire des produits disponibles; Entretiens avec les transformateurs et distributeurs d'insectes
	2. Élimination des barrières à l'essai et à l'achat répété	Évaluation des préférences particulières des consommateurs pour les produits d'insectes	Entrevues en profondeur avec des consommateurs actuels et des non-consommateurs
	3. Identification des enjeux entourant l'adoption récurrente des produits	Études de cas à partir de produits d'insectes actuellement disponibles sur le marché	Tests d'acceptabilité pour des produits allant du prêt-à-manger au prêt-à-cuisiner: questions portant sur l'attrait visuel de l'emballage, la palatabilité, le goût, la disposition à essayer et l'intérêt à acheter le produit

Appendix H – Ethics certificate (project involving tastings)

CERTIFICATION OF ETHICAL ACCEPTABILITY FOR RESEARCH INVOLVING HUMAN SUBJECTS

Name of Applicant:	Didier Marquis
Department:	Faculty of Arts and Science
Agency:	N/A
Title of Project:	Identification ses principaux enjeux de commercialisation des insectes comestibles au Québec
Certification Number:	30012952

Valid From: June 04, 2020 To: June 03, 2021

The members of the University Human Research Ethics Committee have examined the application for a grant to support the above-named project, and consider the experimental procedures, as outlined by the applicant, to be acceptable on ethical grounds for research involving human subjects.

Dr. Richard DeMont, Chair, University Human Research Ethics Committee

Appendix I – Survey questions

Knowledge and experience (Yes/No)

1. Have you ever heard of the practice of eating insects, which is named entomophagy?
2. Were you aware that over a quarter of the world's population commonly eat insects?
3. Were you aware that insects were a sustainable alternative to conventional animal meat?
4. Were you aware that insects could constitute an advantageous nutritional choice as compared to conventional meat?
5. As some insects are omnivorous, did you know that they could help us revaluate our organic wastes into food or feed?
6. Have you ever willingly eaten insects?

    No(A)/Yes(B)

    Since you have never willingly eaten insects...

    A7. Would you try the experience?

    Yes(A)/No(C)

        Since you would be willing to try eating insects...

        A8. It would be... (1 to 5: totally disagree to totally agree)

            By curiosity?
            For your own health?
            For ecological reasons?
            For ethical reasons (animal welfare)?
            As a personal challenge?
            To be noticed?

    Since you have already eaten insects...

    B7. How often do you eat insects?

        Only once (exceptional event)
        Less than once a year
        At leat once a year
        At least once a month
        At least once a week
        At least once a day

    B8. When you have eaten insects, you have done it... (1 to 5)

        By curiosity?
        For your own health?
        For ecological reasons?
        For ethical reasons (animal welfare)?
        Because you were challenged to?
        As a personal challenge?
        To be noticed?

    B9. Would you repeat the experience?

        Yes, I already did
        Yes, probably
        No, I don't think so
        No, never

Since you are open to the idea eating insects... (A&B: preferences and concerns)

A9/B10. Do you think that insects could be an interesting source of protein to replace your meat consumption?

Absolutely
Probably
Probably not
Not at all
I don't eat meat

A10/B11. In what form(s) would you be most willing to eat insects?

Whole
Crushed into pieces
In powder or flour
None

A11/B12. I would rather eat insects incorporated into sweet rather than salty recipes.

1 to 5 (totally disagree to totally agree)

A12/B13. If I had to eat whole insects, I would rather eat crickets (A) than mealworms (B).

1 to 5 (totally disagree to totally agree)

A13/B14. If I had to eat powdered insects, I would rather eat crickets than mealworms.

1 to 5 (totally disagree to totally agree)

A14/B15. I would prefer eating insect-based processed foods rather than cooking them myself.

1 to 5 (totally disagree to totally agree)

A15/B16. I would give great importance to the origin and farming conditions (traceability) of insects before consuming them.

1 to 5 (totally disagree to totally agree)

A16/B17. I would accept to eat insects fed on clean organic waste originating from controlled food transformation processes.

1 to 5 (totally disagree to totally agree)

<u>Since you are not interested in eating insects... (C)</u>

C8. What keeps you from eating insects more regularly? (multiple choices possible)

Their appearance
Their texture
Their taste
Their availability
Their price
The lack of farming and processing standards

Mistrust regarding the origin of products
The fear of getting sick
Other… (provide your response)

General food habits... 1 to 5 (totally disagree to totally agree)
A17/B18/C9. I cook at least once a day using fresh or ideally unprocessed foods.
A18/B19/C10. I consider having a healthy and varied diet.
A19/B20/C11. I am preoccupied by food security issues.
A20/B21/C12. I have a preference for local foods.
A21/B22/C13. I make ecological food choices.

Beliefs regarding edible insects... 1 to 5 (totally disagree to totally agree)
A22/B23/C14. I believe insect farming raises ethical issues that are comparable to those of conventional meat (animal welfare).
A23/B24/C15. I believe humans should eat more insects.
A24/B25/C16. I believe we should put more effort into feeding livestock and/or poultry with insects.
A25/B26/C17. I believe edible insects should be available on grocery stores' shelves.
A26/B27/C18. I am in favor of introducing edible insect farms in controlled environments within cities.
A27/B28/C19. I believe insect farming could be easily integrated into urban agriculture networks.
A28/B29/C20. Between food waste reduction and organic residues composting, I believe valuing clean organic residues with insects could constitute an interesting complementary process.
A29/B30/C21. I believe that the practice of eating insects could grow in North America.
A30/B31/C22. I would be open to the idea of rearing my own insects at home.
A31/B32/C23. I believe that if future generations are made aware of health and environmental issues at a young age, they might further integrate insects in their diet.

Sociodemographic data
A32/B33/C24. You are...
A female
A male
Other
I prefer not answering
A33/B34/C25. To what age group do you belong?
- 18 yo
18-24 yo
25-34 yo
35-44 yo
45-54 yo
55-64 yo
65-74 yo
+ 75 yo
I prefer not answering

A34/B35/C26. Are you currently a student?
Yes

No

A35/B36/C27. What is the highest level of education that you have completed?

None
Elementary
High school
College (between high school and university)
University undergraduate
University master
University doctoral
I prefer not answering

A36/B37/C28. What is your country of origin?

A37/B38/C29. Where do you currently live?

Canada: What are the first three digits of your postal code?
United States
Latin America
Europe
Africa
Asia
Oceania
I prefer not answering

A38/B39/C30. In which interval is your personal income?

Less than 15 000 C$
From 15 000 $ to 29 999 C$
From 30 000 $ to 49 999 C$
From 50 000 $ to 69 999 C$
From 70 000 $ to 99 999 C$
100 000 C$ and more
I prefer not to answer

A39/B40/C31. Where did you hear about this survey?

David Suzuki Foundation
Espace pour la vie
Les Amis de l'Insectarium
Forests Ontario
Commission scolaire de Montréal
Le Soleil
Bob le chef
UQÀM & Laboratoire sur l’agriculture urbaine (AU/LAB)
Concordia Food Coalition
Other… (provide your answer)

A40/B41/C32. Is there anything you would like to add?

Appendix J – Tasting questions

1. Age
2. Have you already eaten insects before?
    a. How often?
    b. What type?
    c. In what form?

For each product:

3. Appearance
    a. On a scale of 1 to 5
    b. Appearance description using keywords (appealingness, expectations, disgust or desire to taste)
4. Odor
    a. On a scale of 1 to 5
    b. Odor description using keywords
5. Taste
    a. On a scale of 1 to 5
    b. Taste description using keywords
6. Texture
    a. On a scale of 1 to 5
    b. Texture description using keywords
7. Willingness to buy the product
    a. On a scale of 1 to 5
8. Probability to adopt the product as part of a regular diet (consumed at least once a week)
    a. On a scale of 1 to 5

Appendix K – Ethics certificate (project involving youngsters)

UNIVERSITÉ Concordia UNIVERSITY

CERTIFICATION OF ETHICAL ACCEPTABILITY FOR RESEARCH INVOLVING HUMAN SUBJECTS

Name of Applicant: Didier Marquis

Department: John Molson School of Business\ Marketing

Agency: Mathematics of Information Technology and Complex Systems

Title of Project: Chirps for thought

Certification Number: 30007979

Valid From: July 10, 2017 to: July 09, 2018

The members of the University Human Research Ethics Committee have examined the application for a grant to support the above-named project, and consider the experimental procedures, as outlined by the applicant, to be acceptable on ethical grounds for research involving human subjects.

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Dr. James Pfaus, Chair, University Human Research Ethics Committee

Appendix L – Youngsters' survey questions in French

Pre-project survey (A) and post-project survey (B) questions
1 à 5: (1) pas du tout; (2) pas vraiment; (3) neutre; (4) oui quand même; (5) oui vraiment

1. (A & B) Tu es…
   - Un garçon
   - Une fille
   - Autre
   - Je préfère ne pas répondre
2. (A) Quel est ton pays d'origine?
3. (A) Es-tu d'accord avec les affirmations suivantes? (1 à 5)
   - 3.1 J'aime essayer des nouveaux/différents aliments.
   - 3.2 Je me méfie des aliments que je ne connais pas.
   - 3.3 Si je ne sais pas ce qu'un aliment contient, je ne le mangerai pas.
   - 3.4 J'aime manger des aliments provenant de pays étrangers.
   - 3.5 Je trouve que la nourriture étrangère est bizarre.
   - 3.6 Quand je mange chez des amis, je suis prêt(e) à essayer des aliments nouveaux.
   - 3.7 J'ai peur de manger des aliments que je n'ai jamais mangés avant.
   - 3.8 Il y a beaucoup d'aliments que je n'aime pas.
   - 3.9 Je mange presque n'importe quoi.
   - 3.10 J'aime essayer des nouveaux restaurants de cuisine étrangère.
4. (A) As-tu déjà entendu parler de la pratique de manger des insectes, que l'on nomme entomophagie? (oui/non)
5. (A) Savais-tu que plus du quart de la population mondiale mangeait des insectes régulièrement? (oui/non)
6. (A & B) Savais-tu (A) / crois-tu (B) que les insectes peuvent représenter un choix nutritionnel avantageux par rapport à la viande conventionnelle? (oui/non)
7. (A & B) Serais-tu prêt à essayer de manger des insectes?
   - J'en ai déjà mangé et je serais prêt à en manger à nouveau.
   - J'en ai déjà mangé mais je ne voudrais pas réessayer.
   - J'en ai jamais mangé mais je serais prêt à essayer.
   - J'en ai jamais mangé et je ne voudrais pas essayer.
8. (A & B) Si je t'offrais de manger des insectes, serais-tu prêt à le faire...? (1 à 5)
   - 8.1 Par curiosité
   - 8.2 Pour ta santé
   - 8.3 Pour des raisons écologiques
   - 8.4 Pour des raisons éthiques (bien-être animal)
   - 8.5 Par défi personnel
   - 8.6 Pour te faire remarquer
9. (A & B) Sous quelle(s) forme(s) aimerais-tu le mieux consommer des insectes (plusieurs choix possibles)?
   - Entiers
   - Broyés en morceaux
   - En poudre ou en farine
   - Aucune

10. (A & B) Je préférerais manger des insectes incorporés à des recettes sucrées plutôt que salées. (1 à 5)
11. (A & B) Si j'avais à manger des insectes entiers, je serais davantage tenté(e) de consommer des grillons (image de gauche) plutôt que des ténébrions (image de droite). (1 à 5)


12. (A & B) Si j'avais à manger des insectes réduits en poudre, je serais davantage tenté(e) de consommer des grillons plutôt que des ténébrions. (1 à 5)
13. (A & B) Je crois que les humains devraient manger plus d'insectes. (1 à 5)
14. (A & B) Je crois qu'on devrait davantage nourrir les animaux avec des insectes. (1 à 5)
15. (A & B) Je crois que les insectes comestibles devraient être disponibles à l'épicerie. (1 à 5)
16. (A & B) Je crois que de plus en plus de gens vont consommer des insectes en Amérique du Nord. (1 à 5)
17. (A & B) Je serais ouvert(e) à l'idée d'élever moi-même des insectes à la maison. (1 à 5)
18. (A & B) En classe, je serais (A) / j'ai été (B) intéressé(e) d'en apprendre plus sur les insectes et leur élevage. (1 à 5)
19. (A & B) Que penses-tu de l'idée (A) / Qu'as-tu pensé du fait (B) d'avoir un élevage d'insectes dans ta classe? (1 à 5)
   19. 1 Ça me (A) / m'a (B) fait peur.
   19.2 Ça me rend (A) / m'a rendu (B) curieux.
   19.3 Je trouve que c'est une bonne idée (A) / J'ai trouvé l'expérience enrichissante (B).
   19.4 Je ne pense pas que les élevages d'insectes ont leur place à l'école (A) / Je serais prêt(e) à répéter l'expérience (B).
20. (A & B) As-tu quelque chose à ajouter?

Appendix M – Original respondents' comments in French

3.1 : « Mes allergies me rendent plus craintif (face) aux nourritures étrangères. »
« Ce serait intéressant d'intégrer les insectes dans notre culture alimentaire:) »

3.2: « Personnellement, j'ai une grande phobie des insectes. Si je n'en avais pas peur, je serais prête à manger des insectes pour ma santé et mon environnement. »
« J'aimerais que nous puissions comparer les insectes à la viande conventionnelle en classe sur plusieurs niveaux. Par exemple, au niveau écologique, au niveau nutritif, au niveau du prix et au niveau gastronomique. »
« Je suis végétarienne et je compte devenir végétalienne, mais si ça a un impact positif sur ma santé, je serais prête à l'essayer. Cependant, un être vivant reste un être vivant, donc pour moi, tuer un insecte, un poisson, un oiseau (ou tout autre animal) reste la même chose. »
« Est-ce que les insectes c'est éthiquement bon pour les véganes? »
« J'ai déjà fait (l'élevage d'insectes) avec des ténébrions et ceci est non seulement éducatif mais vraiment amusant (le mien se nommait Arthur). Bref, j'aimerais vraiment avoir un élevage d'insectes dans ma classe. »
« Je consomme déjà de la farine de grillons. L'idée d'avoir un élevage d'insectes en classe, je trouve ça GÉNIAL. »
« Si je ne suis pas prête à manger des insectes pour le bien-être animal, c'est que je suis déjà végane et que je trouve que ça ne ferait pas de sens de manger d'autres êtres vivants qui peuvent avoir des sensations alors que j'ai déjà exclu ça de mon alimentation. Je serais par contre curieuse d'en apprendre plus sur l'élevage des insectes ainsi que sur son impact écologique. »

3.3 *: « J'ai aimé en manger pour découvrir que finalement ce n'est aucunement dégoûtant ou épeurant. »*
« Une autre dégustation serait bien (quand même sous la forme de farine et non entiers). »
« Les insectes sont la porte de sortie pour couper la viande. »
« On devrait en parler plus afin de sauver le sort de la planète! »
« Il faudrait que la population soit mieux renseignée pour être plus ouvert à en manger. Surtout s'ils ne connaissent pas tous leurs bienfaits. »
« C'était très intéressant de goûter à des insectes parce que sans cela je ne pense pas que je serais allée en acheter pour (y) goûter. »
« C'était un projet très intéressant et innovant! J'espère consommer des insectes plus régulièrement lorsqu'ils seront davantage commercialisés.
« Je trouve que l'éducation par rapport à une alimentation comportant des insectes devrait être obligatoire dans toutes les écoles puisque c'est un excellent moyen de tranquillement sauver notre planète:) »

3.4 *: « Je crois qu'avec le temps, la société devrait s'être habitué à en manger et presque plus personne ne sera dégoûté par les insectes. »*
« Je trouve que l'on devrait faire plus de travail sur le blocage mental des gens lorsqu'ils font face à des insectes et qu'ils trouvent cela répugnant. Pour qu'à la longue les gens ne soient plus dégoûtés. Je trouve que l'on devrait écrire des livres de recettes pour inclure des insectes

ou des ingrédients à base d'insectes (comme la farine ou les spaghettis) pour les dissimuler et faire en sorte que plus de personnes en mangent. »
« Je crois que c'est bien de nous sensibiliser maintenant, car je crois que c'est une option, qui, avec les années va prendre de l'ampleur et de l'importance. De plus, je crois que c'est quelque chose à considérer en tant qu'avancée et solution par rapport aux changements climatiques! »
« J'ai beaucoup aimé cette expérience et j'espère que nous retrouverons davantage d'insectes en épicerie pour pouvoir en consommer au quotidien et même pour pouvoir faire des recettes. »
« Je crois que beaucoup de personnes ont peur d'essayer les insectes et de les incorporer dans leur diète car c'est un aliment inhabituel pour eux. Même moi, qui se prétend ouvert à l'idée de manger des insectes, me retrouve un peu nerveux à cette idée. Par contre, il est possible d'ouvrir l'esprit d'une population à cette pratique en créant des publicités, des dégustations ou en (les) ajoutant dans les épiceries. (Ça) aiderait beaucoup à rendre les gens plus confortables. »

3.5 *: « Je pense que la seule raison pourquoi je refuserais de manger des insectes c'est parce que l'aspect me rebute vraiment, mais s'il était présenté d'une manière à ce qu'on ne puisse pas voir l'aspect de l'insecte alors là je serais peut-être plus poussée à en prendre. »*
« J'aime les insectes au BBQ. »
« Je crois que lorsque vous cuisinez les ténébrions, vous devriez (en) prioriser l'apport nutritif plutôt que le goût (et) essayer d'éviter les sucres et les gras animaux car il y en avait beaucoup dans les recettes présentées. »
« Les grillons sont les seuls insectes que je mangerais dû à leur goût et au fait qu'ils ne me dégoutent pas contrairement aux autres. Je les mangerais en poudre et je trouve qu'ils sont meilleurs accompagnés d'autres aliments (...). »

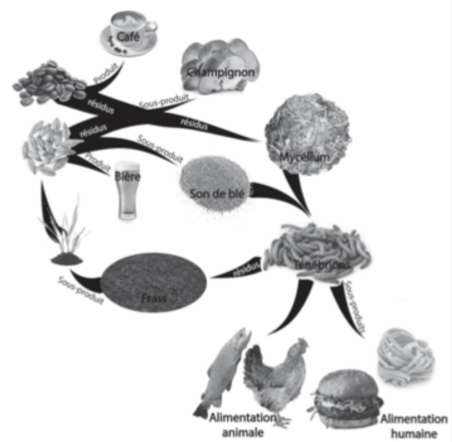
3.6 : « *Vous devriez sensibiliser davantage plusieurs adultes car leur influence sur les jeunes est plus forte et si les familles commencent à être sensibilisés à tous les avantages que les insectes nous proposent et bien je suis sûr que ce sera une habitude grandissante au Québec. »*
« Mon père démarre son projet de farine de criquet. »
« Ça a vraiment changé ma vision que j'avais sur les insectes! J'encourage fortement que vous en parliez plus dans les écoles! »
« J'ai goûté... pas si pire finalement! J'en ai même fait manger à ma famille et ils n'étaient pas au courant! HAHAHAHA »
« On devrait en parler plus en classe et nous devrions faire ce projet avec tous les niveaux pour sensibiliser les gens de tout âge. »
« Continuez de faire des "conférences" dans les écoles, car nous sommes la nouvelle génération et les changements viendront avec nous:) »

Valorisation de résidus de champignonnière urbaine à l'aide des ténébrions meuniers
Un projet d'agriculture urbaine et d'économie circulaire

Marquis, Didier [1], Louise Hénault-Ethier[2], Nathalie R. Le François[3], Stéphane Labelle[3], Marc Fournier[4], Éric Lucas[4], Grant W. Vandenberg[5], Jordan LeBel[1] et Satoshi Ikeda[1]

Contexte

- Le ténébrion meunier (TM) est une espèce phare en entomophagie car: facilité d'élevage, taux de reproduction et facteur de conversion alimentaire élevés, valeur nutritionnelle intéressante, goût apprécié.
- Le TM est détritivore et sa diète d'élevage est généralement composée principalement de son de blé (sous-produit de transformation vendu environ 2$/kg).
- Blanc de Gris (BdG) est une champignonnière urbaine faisant pousser des pleurotes en ville sur des résidus de transformation de café et de bière récoltés à même le quartier Hochelaga-Maisonneuve.

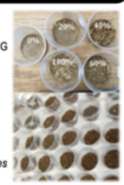


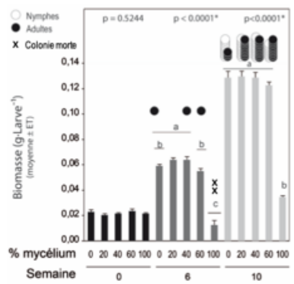
Objectif

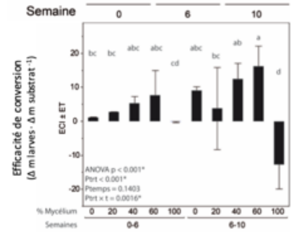
- Valorisation du résidu de production de BdG, un substrat organique « propre » composé principalement de mycélium de champignons en nourrissant des TM.
- Valorisation du résidu d'élevage, un substrat enrichi en déjections et exuvies d'insectes (*frass*), pouvant stimuler la croissance de plantes (expérience à venir), permettant ainsi la création d'un réseau d'économie circulaire.

Expérience A - Petite échelle

- 5 traitements x 5 réplicas
  - A: 0% mycélium (100% Son de blé)
  - B:20, C:40, D: 60, E:80 ou F:100% mycélium BdG
- 25 pots de plastique de 500ml aérés
- 10 larves de TM par pot
- 20 g de substrat (équivalent sec)
  - mycélium = 57% d'humidité à T_0
- Incubateur T° = 27°C; humidité ambiante ~ 40%
- Durée de l'expérience: 10 semaines
- Larves et substrat pesés : semaines 0, 6 et 10
- *Figures: Les moyennes significativement différentes sont représentées par des lettres différentes*



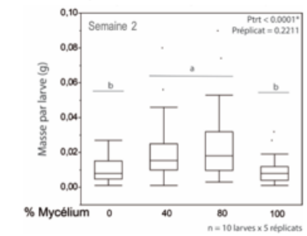


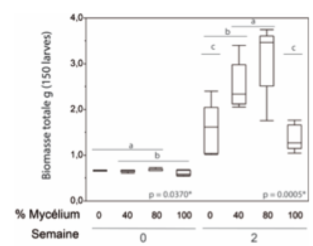


- Croissance TM supérieure à la semaine 6 avec 20% et 40% de substrat BdG mais se rééquilibre à la semaine 10
- Le nombre de nymphes et d'adultes collectés suggère un accomplissement du cycle de vie accéléré avec 20%, 40%, et 60% de substrat BdG
- La mortalité et la biomasse des larves vivantes après 10 semaines suggèrent que TM ne peut se nourrir uniquement du substrat BdG

Expérience B – Moyenne échelle

- 4 traitements x 5 réplicas
  - A: 0% mycélium (100% Son de blé)
  - B: 40, C: 80 ou D: 100% mycélium BdG
- 20 bacs de plastique de 30x60 cm aérés
- 150 larves de TM par bac
- 310g de substrat (équivalent sec)
- Température pièce ~ 23°C
- Humidité relative mesurée inégale
  - A,B,C et D = 30, 30, 40, et 60%
  - contenants de 100 ml d'eau/bac
- Expérience en cours (semaine 4)
- Larves et substrat pesés aux 2 semaines

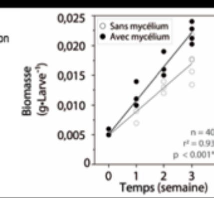




- À la semaine 2, les larves TM individuelles sont plus hétérogènes mais significativement plus massives avec 40 et 80% de mycélium BdG
- Malgré une légère différence dans la biomasse totale en début d'expérience entre le 100% son de blé et le 100% mycélium, cette différence s'estompe à la semaine 2.

Expérience C – Petite échelle

- 2 traitements x 5 réplicas
  - 80% Substrat BdG pré- vs post-inoculation
    - sans et avec mycélium
  - + 20% son de blé
- 10 pots de plastique de 500 ml aérés
- 10 larves de TM par pot
- 20g de substrat (équivalent sec)
- Température pièce ~ 23°C
- 2g d'eau vaporisés chaque semaine
- Expérience en cours (semaine 4)
- 5 larves pesés / semaine



- Croissance TM supérieure aux semaines 1 à 3 avec substrat BdG riche en mycélium

Conclusion

Il est possible d'optimiser l'élevage des ténébrions meuniers en substituant 40 à 80% du son de blé par du substrat enrichi de mycélium de pleurote. Le mycélium améliore la croissance des larves par rapport au substrat pré-inoculation (composé de drêche, marc de café, tiges de chanvre). Ceci suggère un potentiel intéressant pour cette pratique d'agriculture urbaine misant sur l'économie circulaire.

Tableau 1: Analyses fertilisantes du substrat BdG riche en mycélium.

Substrat BdG avec mycélium	% Matière organique	% Azote total	% Phosphore (P_2O_5)	% Potassium (K_2O)	C/N
A (2016/10)	54,03	1,46	0,21	0,38	18,50
B (2016/08)	84	2,77	0,2	0,88	15

À venir

- Compléter les analyses comparatives de composition chimique des résidus d'élevage de TM et de leurs déjections.
- Déterminer le rôle joué par l'humidité du substrat sur la variation du taux de croissance observée.
- Analyses comparatives de la valeur nutritionnelle (protéines, lipides, acides aminés, acides gras, des TM nourris au substrat de BdG).
- Tests d'alimentation avec TM pour certaines espèces de poissons au Biodôme de Montréal et les poules urbaines d'Alvéole.
- Expériences utilisant les résidus d'élevage de TM comme amendement fertilisant pour stimuler la croissance des plantes.

Affiliations

1 Concordia University 2 Fondation David Suzuki 3 Espace pour la vie Montréal 4 Laboratoire Lutte Bio UQÀM 5 Université Laval

Remerciements

Blanc de Gris, Alvéole, Mitacs Accélération — Pour la bourse DM, RECYC-QUÉBEC Québec — Pour la bourse LHE

Appendix O – Frass laboratory analyses

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ENGRAIS ORGANIQUE

Résultats d'analyses

Accrédité par CEAEQ ISO-CEI 17025 pour Mat. Sèche / Organique, Ntot, NH_4, P, K, Ca, Mg, pH

Numéro du certificat: FU-0078901
Date de réception: 12 mars 18
Date du rapport: 28 mars 18
Minéralisation acide, dosage ICP
Résultats en base humide
Numéro d'accréditation : 459
Numéro d'envoi : 74362

Provenance

Échantillonné le

Échantillon

Biodôme de Montréal
4777 Boulevard Pierre de Coubertin
Montréal
H1V1B3

Par :

RÉSULTATS												
		Matériel référence		-		-		-		-		
		Matériel analysé		-		-		-		-		
Méthode	Paramètre	Identification client		1		2		3		4		
		No Laboratoire		Réf.	FU-0078901	Réf.	FU-0078902	Réf.	FU-0078903	Réf.	FU-0078904	
AEL-I-FUM-005	Matière sèche	M.S	(%)		45.6		47.0		92.7		91.7	
AEL-I-FUM-005	Matière organique	M.O	(%)		41.3		38.8		83.0		75.5	
	Densité	D	(t/m3)		0.485 C		0.477 C		0.316 C		0.318 C	
Calcul	Rapport C/N	C/N			32.9		27.2		30.9		30.6	
AEL-I-FUM-005	Azote total	N total	(kg/t)		6.3		7.1		13.4		12.3	
AEL-I-FUM-004	Azote ammoniacal	$N\text{-}NH_4$	(kg/t)		0.01		0.27		0.07		0.15	
AEL-I-FUM-004	Azote nitrate	$N\text{-}NO_3$	(ppm)									
AEL-I-FUM-003 et AEL-I-EQP-028	Phosphore	P_2O_5	(kg/t)		1.4		1.5		6.4		4.6	
	Potassium	K_2O	(kg/t)		3.3		2.4		8.3		5.1	
	Calcium	Ca	(kg/t)		13.9		23.7		58.9		40.5	
	Magnésium	Mg	(kg/t)		0.7		1.2		4.2		2.2	
	Cuivre	Cu	(ppm)		7		9		12		15	
	Manganèse	Mn	(ppm)		23		29		68		63	
	Zinc	Zn	(ppm)		13		14		35		31	
	Bore	B	(ppm)									
	Fer	Fe	(ppm)		88		152		236		504	
	Souffre	S	(ppm)									
	Sodium	Na	(ppm)		151		219		197		279	
	Aluminium	Al	(ppm)		202		248		395		339	
AEL-I-FUM-007	Acidité	pH										

		1	2	3	4
C / N		32.9	27.2	30.9	30.6
NH_4 / N total	%	0.2	3.8	0.6	1.2
Niveau de minéralisation		Faible minéralisation	Faible minéralisation	Faible minéralisation	Faible minéralisation
Disponibilité de l'azote		Faible à négative	Faible à négative	Faible à négative	Faible à négative
N potentiellement disponible	kg/t	0.6	1.4	1.3	1.2

Valeur fertilisante et monétaire du fumier N : P_2O_5 : K_2O : $/kg

Valeur fertilisante du fumier		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Valeur brute	kg/t	6.27	1.36	3.26	7.14	1.47	2.40	13.43	6.35	8.31	12.33	4.56	5.14
Valeur épandu été	kg/t	0.54	0.88	2.94	1.24	0.96	2.16	1.17	4.13	7.48	1.07	2.96	4.63
Valeur épandu automne	kg/t	0.39	0.55	2.38	0.88	0.60	1.75	0.83	2.58	6.07	0.76	1.85	3.76
Valeur monétaire du fumier	tonne	1 t	500 t	1000 t	1 t	500 t	1000 t	1 t	500 t	1000 t	1 t	500 t	1000 t
Valeur brute	$	9.51	4 757	9 513	9.98	4 992	9 984	24.46	12 227	24 464	19.74	9 872	19 744
Valeur épandue été	$	3.14	1 572	3 144	3.44	1 722	3 445	9.58	4 788	9 575	6.66	3 331	6 662
Valeur épandu automne	$	2.34	1 170	2 340	2.50	1 250	2 501	6.92	3 461	6 921	4.77	2 387	4 774

1642, de la Ferme, La Pocatière (Québec) G0R 1Z0
Tél. : 418 856.1079 Téléc. : 418 856.6718
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www.agro-enviro-lab.com

Michel Champagne, agronome

Karin Arseneault, chimiste

AgroEnviroLab

ENGRAIS ORGANIQUE

Résultats d'analyses

Accrédité par CEAEQ ISO-CEI 17025 pour Mat. Sèche / Organique, Ntot, NH_4, P, K, Ca, Mg, pH

Numéro du certificat: FU-0078905
Date de réception: 12 mars 18
Date du rapport: 28 mars 18
Minéralisation acide, dosage ICP
Résultats en base humide
Numéro d'accréditation : 459
Numéro d'envoi : 74362

Provenance

Échantillonné le

Échantillon

Biodôme de Montréal
4777 Boulevard Pierre de Coubertin
Montréal
H1V1B3

Par :

RÉSULTATS		Matériel référence			-		-		-	
		Matériel analysé			-		-		-	
Méthode	Paramètre	Identification client			8		5		7	
		No Laboratoire		Réf.	FU-0078905	Réf.	FU-0078906	Réf.	FU-0078907	
AEL-I-FUM-005	Matière sèche	M.S	(%)		91.5		91.3		91.2	
AEL-I-FUM-005	Matière organique	M.O	(%)		78.1		86.1		81.8	
	Densité	D	(t/m3)		0.319 C		0.319 C		0.320 C	
Calcul	Rapport C/N	C/N			24.6		14.9		17.0	
AEL-I-FUM-005	Azote total	N total	(kg/t)		15.9		28.9		24.0	
AEL-I-FUM-004	Azote ammoniacal	$N\text{-}NH_4$	(kg/t)		0.19		0.29		0.23	
AEL-I-FUM-004	Azote nitrate	$N\text{-}NO_3$	(ppm)				5.5		5.9	
AEL-I-FUM-003 et AEL-I-EQP-028	Phosphore	P_2O_5	(kg/t)		7.7		26.3		18.7	
	Potassium	K_2O	(kg/t)		7.0		15.6		12.5	
	Calcium	Ca	(kg/t)		35.4		1.2		15.9	
	Magnésium	Mg	(kg/t)		2.4		3.4		3.0	
	Cuivre	Cu	(ppm)		14		14		16	
	Manganèse	Mn	(ppm)		78		162		130	
	Zinc	Zn	(ppm)		40		103		79	
	Bore	B	(ppm)							
	Fer	Fe	(ppm)		228		158		217	
	Souffre	S	(ppm)							
	Sodium	Na	(ppm)		261		169		232	
	Aluminium	Al	(ppm)		336		59		247	
AEL-I-FUM-007	Acidité	pH								

		8	5	7	
C / N		24.6	14.9	17.0	
NH_4 / N total	%	1.2	1.0	1.0	
Niveau de minéralisation		Faible minéralisation	Bonne minéralisation	Bonne minéralisation	
Disponibilité de l'azote		Faible à négative	Bonne à élevée	Bonne à élevée	
N potentiellement disponible	kg/t	4.8	14.5	9.6	

Valeur fertilisante et monétaire du fumier N : P_2O_5 : K_2O : $/kg

Valeur fertilisante du fumier		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Valeur brute	kg/t	15.88	7.69	7.04	28.92	26.27	15.63	24.04	18.67	12.45			
Valeur épandu été	kg/t	4.13	5.00	6.34	12.55	17.08	14.07	8.34	12.13	11.21			
Valeur épandu automne	kg/t	2.94	3.12	5.14	8.92	10.67	11.42	5.93	7.58	9.10			

Valeur monétaire du fumier	tonne	1 t	500 t	1000 t	1 t	500 t	1000 t	1 t	500 t	1000 t	1 t	500 t	1000 t
Valeur brute	$	27.41	13 707	27 413	63.25	31 627	63 254	49.24	24 621	49 242			
Valeur épandue été	$	12.68	6 342	12 685	37.21	18 604	37 208	26.59	13 297	26 594			
Valeur épandu automne	$	8.99	4 496	8 992	25.91	12 953	25 906	18.59	9 296	18 592			

1642, de la Ferme, La Pocatière (Québec) G0R 1Z0
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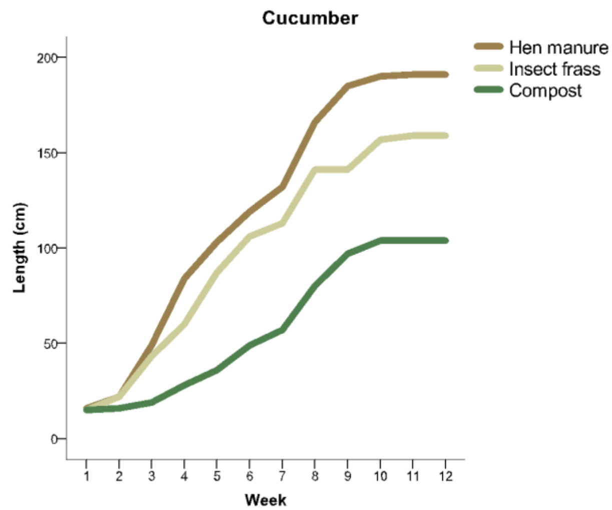
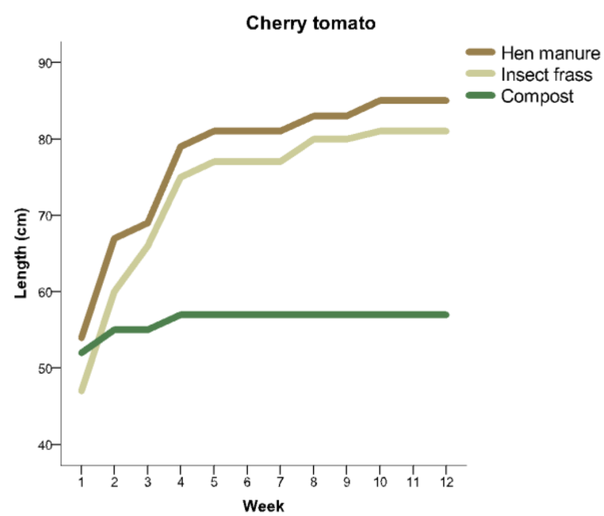
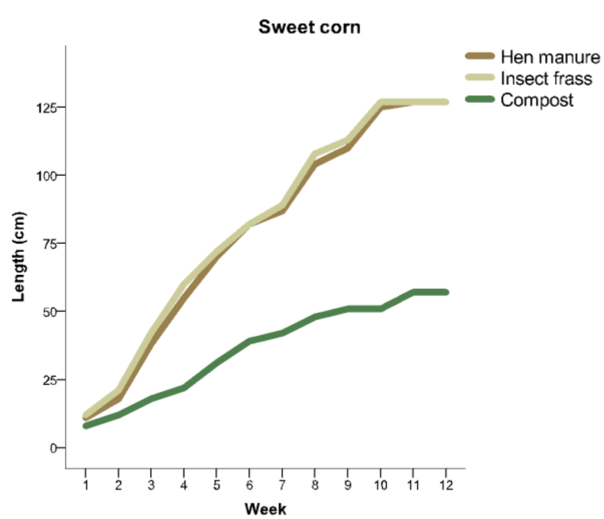
Michel Champagne, agronome

Karin Arseneault, chimiste

Appendix P –Plant growth experiments: graphic results for three species







Appendix Q – Specifications for insect rearing

In a 500-square-foot farming area, it is possible to stack 1200 plastic tote boxes (46cm x 32cm x 11cm = 1471cm^2) for insect rearing.

- 8 rows x 10 shelves x 15 totes = 1200 totes

This arrangement includes:

- 20cm floor clearance for easy cleaning
- 5cm vertical spacing between the totes to allow air movement
- 2m maximum height to allow arm's length manipulations

For optimal productivity, the room temperature must be maintained between 25-30°C and its relative humidity between 50-75% (Chen & Liu, 1992; Manojlovie , 1988).
In order to continually keep the farm at 100% capacity, approximately 1/8th of the rearing space must be dedicated to insect reproduction:

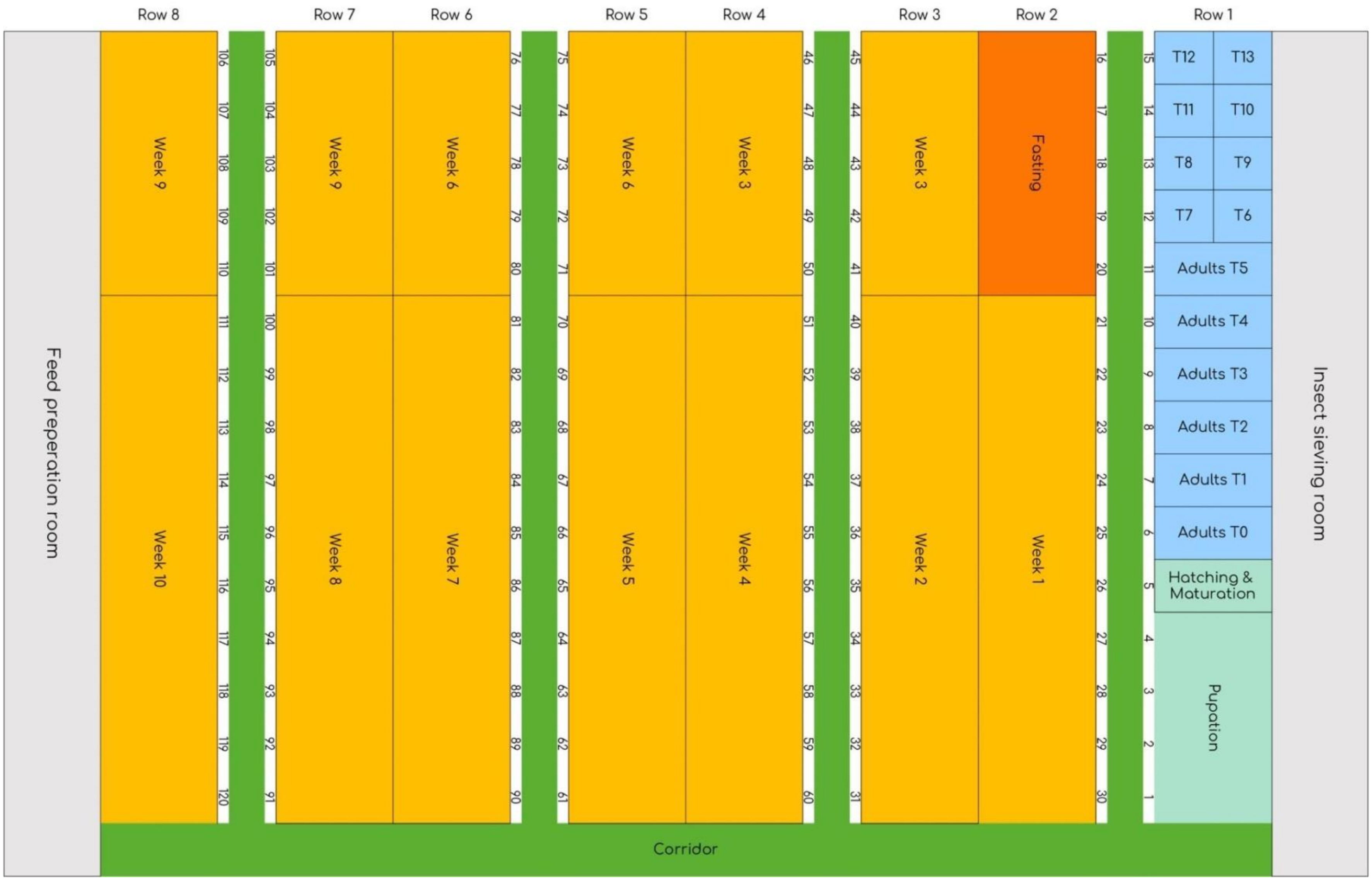
- 1000 totes for larvae growth
- 150 totes for insect reproduction (nursery)
- 50 totes for larvae fasting (prior collection)

<u>Nursery</u>
Note: * means that the provided numbers are based on personal observations made while working at TriCycle's urban farm

1. Breeding: 100 totes

- 10 new breeding totes containing 150g of beetles are created each week
    - Target of 0.84 living beetles per cm^2 (Berggreen et al., 2018)
      (1236 living beetles per 1471cm^2 tote) + 20% average adult mortality in breeding totes* = total density target of 1 adult per cm^2
    - Average of 0.1g per adult* x 1 adult per cm^2 x 1471cm^2 per tote = 147.1g of beetles per new breeding tote (rounded to 150g)
- Dry feed as egg laying substrate
    - 300g once per week x 100 breeding totes = 30kg of dry feed required per week
- Wet feed to avoid beetles from drying
    - 100g thrice per week x 100 breeding totes = 30kg of wet feed required per week
- Breeding totes are sifted weekly using a sifter standard no.20 (850µm openings; Morales-Ramos et al., 2019)
    - Beetles are transferred in a new breeding tote with another 300g of dry feed
    - Beetles breed for 14 weeks*
        - To compensate adult mortality, 2 x 150g of beetles are merged together at week 6
        - Each week, 10 new breeding totes are generated (T0), 10 are merged (T5) and 5 are eliminated (T14)
    - 100 totes containing the sifted substrate (and eggs) are transferred to the larvae growth section

Figure 27. Proposed configuration for a 500-square-foot insect farm



2. Hatching and maturation: 10 totes

To produce these 1.5kg of beetles per week (10 breeding totes per week x 150g of beetles), 2kg of pupae must be collected (75% of them can successfully hatch*)

- Pupae take up to 2 weeks to hatch
- 10 totes of 400g of pupae (optimal density to promote hatching*) will generate 3kg of beetles within 2 weeks
- Two paper towels allow to efficiently collect young beetles while one egg crate can prove efficient for mature adults (black) as they like to hide
- Each week, 5 new hatching totes are generated and 5 are eliminated
- Young beetles are collected from hatching totes thrice a week to prevent cannibalism
- Hatching totes can be merged after 10 days to create shelf space: collected young beetles are transferred into two maturation totes
    - Maturating totes are sprayed with water thrice a week to prevent beetles from drying

3, Pupation: 30 totes

To produce these 2kg of pupae per week, about 12kg of large larvae are needed

- A density of 300g of larvae per tote enhances pupation (2/3 pupating within 4 weeks)*
    - 12kg of larvae x 2/3 pupating / 4 weeks = 2kg of pupae per week
    - 12kg / 300g per tote = 40 pupation totes
- After 10 weeks of growth, harvested larvae are graded using a sifter standard no.6 (3.35mm openings; Morales-Ramos et al., 2019) in order to collect 12kg of large for larvae intended for reproduction (genetic selection)
- Pupation totes are sifted twice a week using a sifter standard no.5 (4mm openings; Morales-Ramos et al., 2019) to collect pupae
- Dry feed required by pupating larvae (using the feed conversion efficiency [FCE] explained in the larvae feeding section below; van Broekhoven et al., 2015)
    - 300g / 1500g of larvae x 1350g of feed = 270g x 20 breeding totes (0-2 weeks) = 5400g
    - 200g / 1500g of larvae x 1350g of feed = 180g x 20 breeding totes (2-4 weeks) = 3600g
    - 5400g + 3600g = 9 kg of dry feed needed per week
- Wet feed (80% moisture) required by pupating larvae
    - 270g / 3 = 90g of feed thrice per week x 20 breeding totes (0-2 weeks) = 5400g
    - 180g / 3 = 60g of feed thrice per week x 20 breeding totes (0-2 weeks) = 3600g
    - 5400g + 3600g = 9 kg of wet feed needed per week
- After 4 weeks of pupation, the remaining larvae that haven't pupated are transferred to fasting for harvest as they might have weaker genetics
    - Frass is collected using a sifter standard no.35 (500µm openings; Morales-Ramos et al., 2019)
        - (9 kg of dry feed + (9kg of wet feed x [20% dry weight]) x (1 – 1 / 3.6 FCE) = 7.8kg of frass produced per week
    - Larvae are separated from residual feed using a sifter standard no.20 (850µm openings; Morales-Ramos et al., 2019)
    - Residual feed can be used once again as mealworm feed

4. Larvae growing: 1000 totes

- Each female adult lays an average of 6.5 eggs per day (Punzo & Mutchmor, 1980)
    - o 1236 living beetles / 2 = 618 living female beetles per tote x 6.5 eggs per day x 7 days = 28 119 larvae per tote
    - o It is estimated that 70% of these eggs will survive (cannibalism or non-hatching)*: 28 119 larvae x 70% = 19 683 larvae per growth tank (rounded to 20 000 larvae)
- After 10 weeks of growth, larvae attain a harvestable size (> 75mg)*
    - o 20 000 larvae x 75mg = 1.5kg x 100 growing totes = 150kg of larvae produced weekly
    - o 3kg are transferred for pupation: 2kg pupate and 1kg is harvested after 4 weeks
    - o 150kg – 2kg = 148kg of larvae harvested weekly

Feeding larvae

- Over the course of their lifespan, mealworm larvae must consume 3 times their weight in dry feed and the twice in wet feed (Coudro et al., 2019)
    - o Dry feed (dehydrated organic by-products containing on average 80% moisture):
        - ▪ FCE = (3 / 0.2) or 15 : 1
    - o Wet feed (still using by-products containing 80% moisture):
        - ▪ FCE = (2 / 0.8) or 2.5 : 1
    - o Total FCE = 17.5 : 1
        - ▪ 1.5kg of larvae must consume over the course of their lifespan:
            - 4.5kg of dry feed (or 22.5kg of wet organic by-products)
            - 3kg of water (or 3.75 kg of wet organic by-products)
    - ▪ Dry feed is distributed once a week while wet feed is distributed thrice a week to maintain moisture in the totes
        - ▪ Prior to week 6, larvae feed on the substrate in which they hatched (5%)
        - ▪ week 6: 5% of dry feed (225g) and 10% of wet feed (3 x 125g)
        - ▪ week 7: 10% of dry feed (450g) and 10% of wet feed (3 x 125g)
        - ▪ week 8: 20% of dry feed (900g) and 20% of wet feed (3 x 250g)
        - ▪ week 9: 30% of dry feed (1350g) and 30% of wet feed (3 x 375g)
        - ▪ week 10: 30 % of dry feed (1350 g) and 30% of wet feed (3 x 375g)
    - ▪ Total feed required weekly:
        - ▪ Dry: (225g + 450g + 900g + 1350g + 1350g) x 100 totes =
          427.5kg of dry feed needed per week
          (or 1710kg of wet organic by-products)
        - ▪ Wet: (375g + 375g + 750g + 1050g + 1050g) x 100 totes =
          360kg of wet feed needed per week
          (or 450kg of wet organic by-products)

5. Fasting (optional): 50 totes

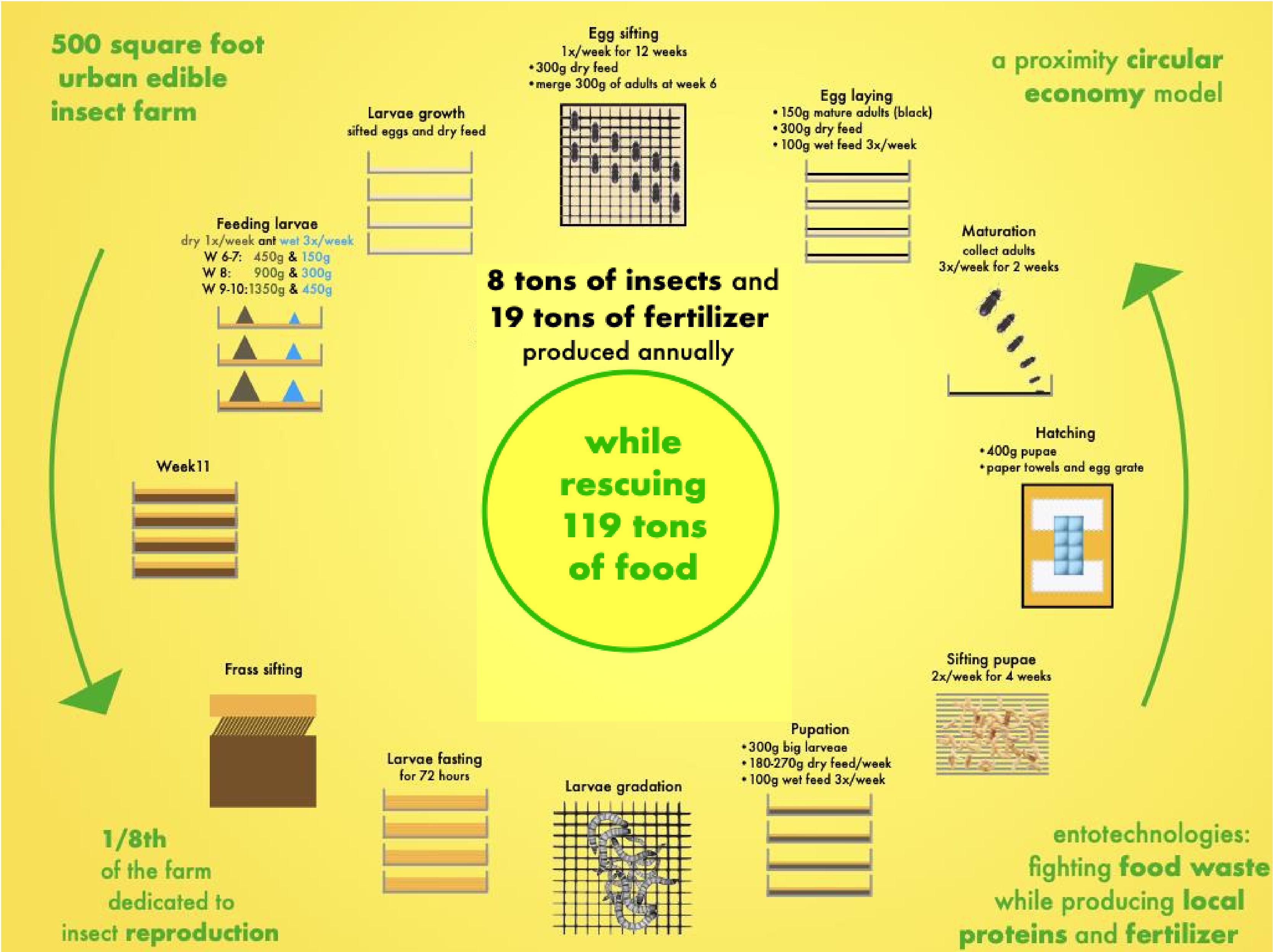
Before harvesting larvae, sifting the substrate present in the plastic totes and allowing larvae to fast is believed to improve flavor and preservation

- Each week, 100 growing totes are collected (at the end of week 10) and their frass is sifted
- Two harvested larvae totes are merged to create a total of 50 fasting totes
- Fasting totes are kept on shelves for 72 hours before being processed (boiled and frozen)
    - (450kg of dry feed consumed + [450kg of wet feed x [20% dry weight]) x (1 – 1 / 3.6 FCE) = 362.14 kg of frass produced per week

Compiled annual data: inputs and outputs

- Feed consumed
    - Dry: 30kg (breeding) + 9kg (pupation) + 427.5 kg (growing) x 52 weeks = 24 258 kg (or 97 tons of organic by-products at 80% moisture)
    - Wet: 30kg (breeding) + 9kg (pupation) + 360kg (growing) x 52 weeks = 20 748kg (or 26 tons of organic by-products at 80% moisture, thus simultaneously providing the equivalent of 4150 kg of dry feed)
    - Total organic by-products required: 97 tons + 26 tons – 4.15 tons = 119 tons
- Edible insects produced
    - 148kg x 52 weeks = 7 696kg of fresh larvae
- Fertilizer produced
    - 7.8kg (pupation) + 362.14kg (growing) x 52 weeks = 19 237kg of frass

Figure 28. Farming operations for a 500-square-foot insect farm



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