Are insects the future of food for Singapore?

Southeast Asia
Centre of Asia-Pacific
Excellence

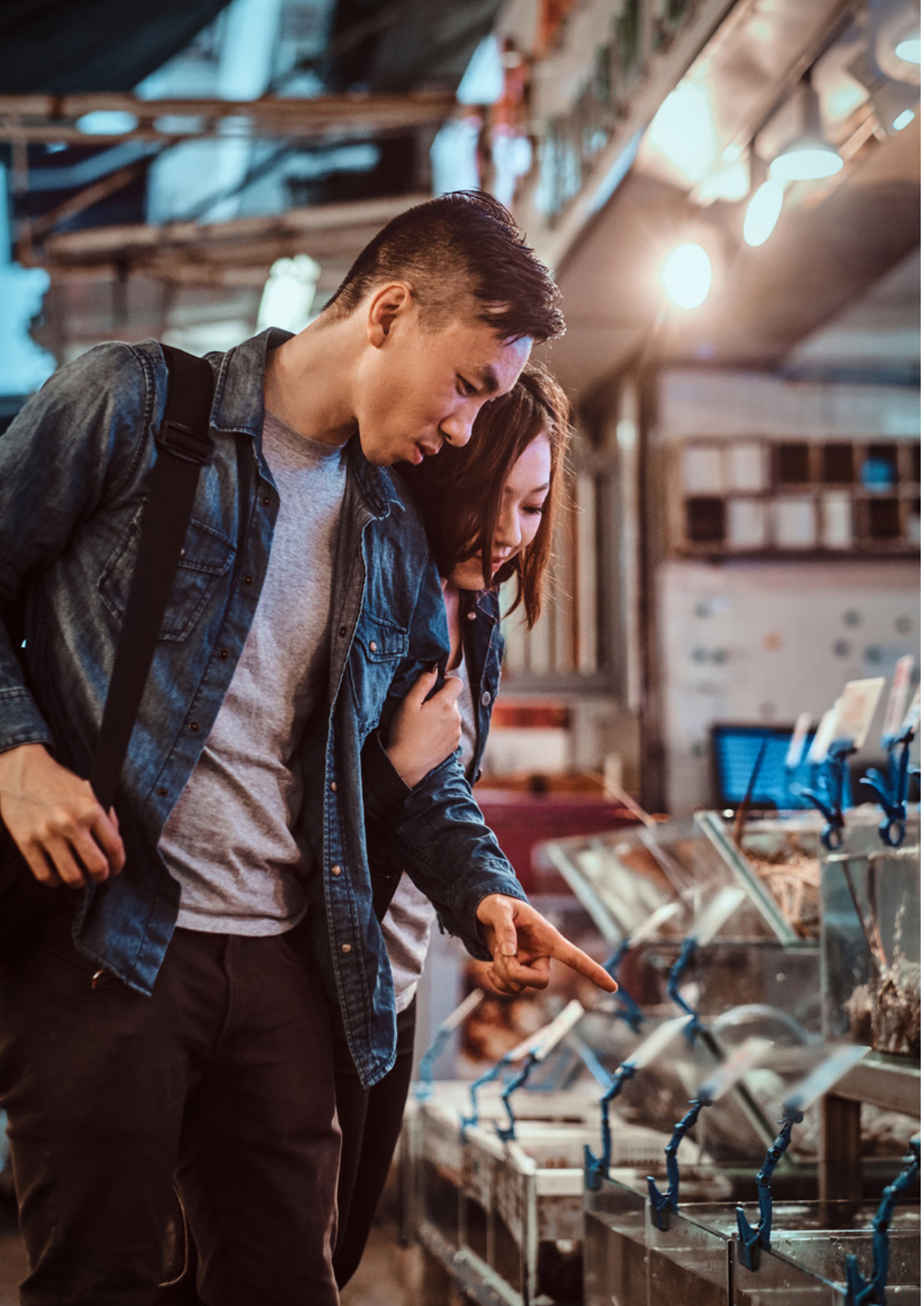
Executive summary

The COVID-19 pandemic has highlighted the need for Singapore to improve self-sufficiency and reduce dependency on international trade. Domestic capability is particularly a concern for the country's food security. Singapore is working to establish solutions that balance consumer demand for nutritious foods and the need for sustainable foods that are innovative and high in protein. Despite Singapore's reputation for business acumen and innovation, it currently struggles to produce food, especially protein, domestically.

New Zealand has a world-renowned reputation for food science research and development (R&D). Our agricultural sector is particularly strong in genetics and breeding, and has produced valuable livestock breeds and plant varieties. The isolated island nation has over 20,000 species of insects, 90% of which are classified as endemic.

This report presents the opportunity for New Zealand and Singapore to create a joint venture in the vertical farming of crickets. This would help Singapore develop better domestic protein production options and help New Zealand diversify its economy and gain market share in the alternative protein market.

Specifically, we explore cross-breeding a superior cricket species in New Zealand to meet both nutritional and sustainability demands. The developed insect variety could be licensed to Singapore farms, and continually developed in New Zealand. Crickets are nutrient dense and provide a valuable source of protein, micronutrients, and bioactive peptides that may aid in the treatment of Type 2 diabetes, obesity and heart disease.



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Background

Singapore's food insecurity

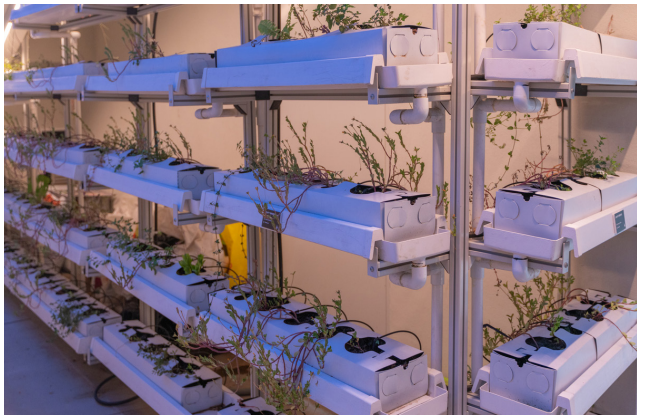
Singapore is a small island nation in Southeast Asia, widely regarded as an innovation hub. Singapore is just 700 km², but it is the third most densely populated country in the world with 5.9 million people (World Population Review, 2022a). This high population density, along with the subsequent lack of land and natural resources, heavily influence Singapore's strategic direction (Quah, 2018), requiring the country to be dependent on international trade and innovation.

Singapore currently imports approximately 90% of its food, and it faces numerous challenges in decreasing trade reliance and increasing sustainable domestic food production (Singapore Food Agency, 2020). Singapore does not have the land area required for traditional agricultural production, and so technological innovations, such as vertical farming, may be needed (Mok et al., 2020). The importance of food security and reducing Singapore's dependence on trade has been further underlined by the Ukraine-Russia conflict and the COVID-19 pandemic, which has caused chicken shortages, high food prices, and supply chain disruptions (Kroll, 2022; Ratcliffe, 2022).

While these issues have not been limited to Singapore, they have been especially acute here because just 10% of food is produced domestically. Singapore therefore faces immense pressure to secure and stabilise food production and supply chains. Its limited resources mean it can only produce a small percentage of domestically consumed vegetables, eggs and fish (Singapore Food Agency, 2020). Singapore imports all other foods, especially macronutrients like protein, with S$393 million (NZ$460 million) of meat imported in 2020 (Stojkovic, 2020).

To address national sustainability challenges, the Singapore government has established the "Singapore Green Plan 2030", which sets the ambitious target of "30 by 30", or domestically producing 30% of the nation's food by 2030. Production will be constrained by the plan's other sustainability goals, such as the reduction of household water consumption to 130 litres per capita per day. In addition, the competition for land within Singapore is extremely high, with core demands from residential and industrial agencies leaving less than 1% of land for agricultural developments (New Zealand Ministry of Foreign Affairs, 2018).

Singapore began experimenting with vertical farming about a decade ago, launching the world's first low-carbon, water-driven, rotating vertical farm. It was used to produce tropical vegetables and aimed to increase the awareness and popularity of environmentally friendly urban farming techniques (Our World, 2021). In more recent years, vertical farming has been expanded to insects, using less water and space than conventional farming practices (Specht et al., 2019). Grasshoppers and mealworms are popular species for farming because of their low greenhouse gas emissions (Oonincx et al., 2010).



New Zealand's opportunity

New Zealand has a similar population to Singapore, but its land area is 373 times greater (World Population Review, 2022b). Like Singapore, New Zealand also has a strong reliance on international trade, but it differs in having core competencies in primary industries, especially agrifood production, horticulture and agriculture. New Zealand's exports are 81.8% agricultural-based, and agri-business accounts for 10.5% of GDP (New Zealand Ministry for Primary Industries, 2022a).

New Zealand has developed highly innovative research and development capabilities in plant and animal sciences to support its primary industries (New Zealand Ministry for Primary Industries, 2014). It is also facing pressure to create more sustainable and value-added products to diversify away from a historic dependence on animal agriculture and pastoral farming. The New Zealand government's new agrifood strategies, including Te Taiao, Fit for a Better World Framework and the Sustainable Food and Fibre Futures Fund (SFF), demonstrate the country's commitment to sustainability (New Zealand Ministry for Primary Industries, 2022a; Primary Sector Council, 2020).

For decades, New Zealand has struggled to break its traditional reliance on commodity markets, despite many advocating for a value over volume strategy (Green, 2021). R&D, especially in the export of services, presents immense opportunities to seek higher value returns, to lower environmental impacts, and to diversify the New Zealand economy (Woods, 2019).

Market analysis

While current consumer resistance to ‘entomophagy’ (the practice of eating insects) is a notable barrier to widespread acceptance, insects have been a part of human diets for thousands of years. Insect consumption has rapidly increased in popularity in developed countries over the past decade. The Asia-Pacific region has been experimenting in the edible insect space for many years, and now insects appear to be gaining traction in European and American markets. Multiple start-ups are attempting to disrupt markets globally, while others are taking a more technological approach to the development of alternative nutrition sources (Yen, 2015).

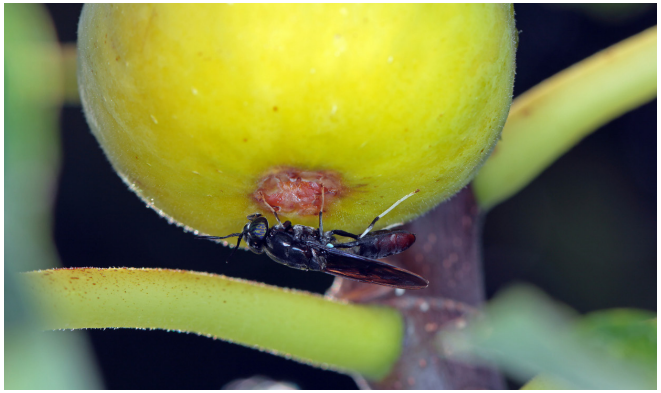
The global edible insect market is forecast to reach S$12.69 billion (NZ$14.93 billion) by 2030, with a compound annual growth rate (CARG) of 28.3% between 2022-2030. Key drivers of this growth are concerns for greenhouse gas emissions from livestock and poultry, the nutritional profile of insects, the environmental benefits, and the minimised risk of zoonotic disease transmission (Research and Markets, 2022). Statistics for the edible insect market in Singapore specifically are not available given their short market history (Mancini, 2022), but the CAGR of edible insects in the Asia-Pacific region was forecast to grow by 22% between 2018 and 2023 (Shahbandeh, 2018). Currently the largest share of the global edible insect market is the whole insects market (Elorinne et al., 2019). These are readily available and cheaper than processed insect products due to the elimination of intensive processing, which lacks facilities in many regions (Elorinne et al., 2019).

Insects as food in Singapore

With growing food security concerns and nutrition demands, Singapore needs to source efficient and sustainable food solutions. In Singapore, crickets are not a traditional food, but they are considered “edible insects for beginners” (Trang, 2021) as they provide a nutty, earthy flavour and minimal aftertaste. The use of New Zealand insect species could create high demand in the Singapore market due to the existing trust and reputation for New Zealand products (Dyer et al., 2020).

A current example of successful insect production in Singapore is Insectta, the first established urban insect farm for the black soldier fly *(Hermetia illucens)*. The flies are reared and used to convert food waste from the brewing industry and soy factories into biomaterials for industrial purposes. Within 24 hours, one kilogram of fly larvae processes four kilograms of waste. The extracted biomaterials such as chitosan and melanin are used in electronics, pharmaceuticals, and cosmetics (Anwar, 2021).

Singapore is ready to invest in the vertical farming of insects. The Singapore-based insect firm Asia’s Nutrition Technologies raised over S$26 million (NZ$31 million) in capital in September 2022 to support the production of new products, increase R&D, and create strategic partnerships (The Fish Site, 2022).



Insect farming in New Zealand

The New Zealand economy has historically been dominated by its primary industries, and the constituent sectors are still widely considered to be the 'backbone' of the economy today. New Zealand has been trying to diversify its export destinations, products, and strategy for a number of decades to reduce the nation's exposure to commodity markets. Increasing environmental sustainability concerns have added further pressure to evolve from dependency on animal agriculture and to create 'value-added' products.

The development of the global insect nutrition market presents a unique opportunity for New Zealand to prioritise value over volume and improve export sustainability. With a global reputation for innovation and R&D capabilities in genetics and breeding, New Zealand has an opportunity to become world-leaders in the edible insect space by commercialising selectively bred insects. While overall R&D spend is low in New Zealand, the country has a history of success in agriculture, food science, and horticulture R&D.

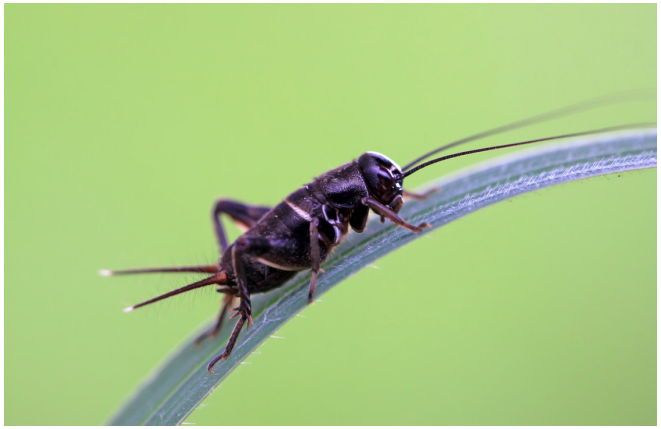
New Zealand also has experience in developing foods to suit consumers in particular markets. For example, the kiwifruit breeding centre, a Zespri and Plant & Food joint venture, has led to the creation of kiwifruit varieties such as SunGold and RubyRed (Plant & Food Research, 2021). SunGold has generated significant returns and its success is directly attributed to its incorporation of market-based consumer demands as observable traits in the fruit.

An AgResearch study (2019) identified the young or 'nymph' of the New Zealand black field cricket *(Teleogryllus commodus)* as having particularly desirable qualities, such as a "crunchy" texture, for New Zealand consumers. Over 67% of respondents stated they would consume crickets processed into flour, while a smaller number would also consume pan-fried crickets (AgResearch, 2019).

A consumer-led development approach could determine whether the species would also appeal to consumers in Singapore.

While not yet widespread, innovative New Zealand firms are showcasing the potential for commercial insect farming. Here are some of the companies already farming insects in New Zealand:

1. Bugfarm have been selectively breeding mealworms for several years, using controlled environments to ensure the insects are large, vigorous and of the highest quality for animal feed (Nichols, 2021).
2. iNZect Direct are "actively working to create and provide innovative, sustainably produced and packaged products to New Zealand's growing insect marketplace". They produce both black field crickets and black soldier fly larvae for wholesale and retail outlets. iNZect Direct also sell a grass fertiliser byproduct of the insect production.



The opportunity for vertical insect farming in Singapore

Insects are considered a sustainable source of protein, chitin, vitamins and minerals (Kouřimská & Adámková, 2016). These nutrients require minimal water, food, and land to produce, while creating very low carbon emissions. These core attributes highly align with the food and environmental sustainability goals set by the Singapore government (Choi et al., 2019).

New Zealand research and development capabilities

New Zealand conducts numerous, extensive, and world-leading R&D programmes, particularly in the agrifood industry (New Zealand Ministry of Business, Innovation and Employment, 2022). Programmes include privately funded R&D at companies like Fonterra and Zespri, as well as publicly funded research at organisations and Crown Research Institutes (CRIs) such as Plant & Food Research, AgResearch, the Food Innovation Network, and Callaghan Innovation. Callaghan has particular expertise in disruptive technology and agrifood innovation, and it helps companies by creating research partnerships with government partners, CRIs and academic institutions (Callaghan Innovation, 2022).

Developing insect breeds

New Zealand could leverage its strong R&D capabilities in agrifood to selectively breed a cricket variety suited for consumption in Singapore (Hendrix, n.d.). New Zealand has a variety of cricket breeds that are efficient reproducers and nutrient-dense, providing a great starting point for selective breeding. Indicative research suggests that crickets are suitable for farming (Reverberi, 2020), and the black field cricket at its nymph stage has been found to be particularly suitable (AgResearch, 2019).

CRIs such as AgResearch could conduct a similar study in Singapore to examine insect preferences there. This could be used to determine which traits insect breeders in New Zealand should consider, to ensure the insects meet Singapore's consumer demands (AgResearch, 2019).

Once an insect species has been selected, it will be important to selectively breed for high nutritional yield. This will include achieving a balance of mass, protein, micronutrients, and chitin content. Breeders may also breed for the bioactive peptides found in many insects that treat some of the common symptoms of Type 2 diabetes.

Product development

The black field cricket nymphs require two to four months to mature, and they live for another three to four months (Agresearch, n.d.). R&D will need to explore how a vertical farming environment can be designed to maximise the production rate of nymphs. Agresearch has the capabilities, resources and connections to complete this research (Agresearch, n.d.), by using the work completed to date on the species as a starting point for further development.

We recommend developing a marketable intellectual property (IP) document to protect any research that is conducted. The IP produced will be able to be licenced to companies with an implementation plan to show how to get the best quality product with the highest production rate.

The subsequent creation of vertical farms in Singapore will help to scale the vertical farming of insects there to produce greater quantities of insects to improve the health of Singaporean citizens.

Cricket nutrient profile

The advantages of crickets as an alternative protein source include their high protein and energy content and their circular sustainability. Processed cricket powders are a complete and clean source of digestible protein, with nine essential amino acids, omega fatty acids, and polyunsaturated acids (Home, 2022). Crickets have rich micronutrients, including calcium, potassium, magnesium, phosphorus, sodium, iron, zinc, manganese, and copper, as well as folic acid, pantothenic acid, riboflavin, and biotin (Magara et al,. 2021).

A key nutritional component of many insects is chitin, which varies in concentration depending on the species, developmental stage, and insect age (Psarianos et al., 2022). Chitin is known for its antioxidant, antimicrobial and antitumor health properties. It is also insoluble and contains a significant quantity of fibre (Magara et al,. 2021). Chitin may also benefit gut microflora, increase immune defences and decrease inflammation (Elieh Ali Komi et al., 2018). These health properties are why insect powders are often used in Traditional Chinese Medicine (TCM).

There is currently limited public information on the nutritional composition of New Zealand cricket species, so we recommend that a nutritional analysis is conducted on a range of cricket life stages. The nutritional composition of a processed cricket product can also be affected by the processing method (e.g., drying, roasting, or smoking).

Waste management

Two major waste streams are produced throughout the insect's life cycle: frass (insect faeces and uneaten food) and exuviae (malted/shedded insect skin; Wageningen University & Research, 2022). Frass is rich in nitrogen and can be used as a fertiliser (Open Access Government, 2022). The exuviae is high in chitin, which reacts with microbes that are affiliated with plant roots to protect the plant against disease (Wageningen University & Research, 2022).

Both waste streams are closely linked, and they can be used to create a fertiliser for crops, where the waste stream of food may be removed for insect feed. This allows the creation of circular production as all waste streams from the insects can be used in crop production and crop waste streams in insect farming. This is closely linked with the production of leafy greens in vertical vegetable farming in Singapore, where the majority of the insect's food will come from their waste streams. Insect-based fertiliser is used to help increase plant growth, building on a stronger aspect of the circular economy in Singapore by utilising multiple waste streams.

The frass and exuviae waste will not be removed until the insects are ready to be harvested. A sieve-like system can be used to split the exuviae and frass from the insects, so contamination does not occur between the product and waste streams for testing and production.

Sustainability considerations

Compared to livestock, insect rearing has a lower environmental impact, requiring significantly less water and land, and producing lower greenhouse gas emissions (UK Centre for Ecology & Hydrology, 2022). A study that quantified the direct emissions from the respiration and metabolism of five different insect species and their faeces found that levels were lower than those of conventional livestock (Oonincx et al., 2010). Life cycle assessments are required for the specific insect species that is farmed to quantify its environmental impact through the entire supply chain (Van Huis & Oonincx, 2017).

The greenhouse gas emissions from poultry production are 89% higher than crickets on an edible protein basis (Halloran et al., 2017). Increasing the percentage of food that is produced locally means food has to travel less distance and transport emissions are decreased (CNA, 2022).

Because insects are poikilothermic, meaning their internal temperature varies considerably, they have a high feed conversion rate. It takes a lot of energy to maintain the ambient temperatures needed in insect farms during rearing. However, insect farming requires less atmosphere control and lighting than vertical plant farming (Van Huis & Oonincx, 2017). High efficiency relies on select diets for the insects' nutritional requirements to be optimised through genetic selection (Oonincx et al.; 2015).

Insects have omnivorous diets, creating the potential to use post-consumer and post-processed food, and crop and fauna waste, for insect rearing in vertical farms. This could create a sustainable feed for insects and reduce waste streams from consumers and producers. The design of renewable and energy-efficient facilities alongside the efficient use of feed ingredients will ensure that the environmental impacts of insect production are minimised in the future (Halloran et al., 2016).

Potential barriers

There are a number of risks and limitations to the development and export of insects and insect products. Some are relevant to both New Zealand and Singapore, while others are country-specific.

1. The lack of awareness of the benefits of insect consumption is currently a limitation to the industry's growth potential. Small studies have expressed the younger generational acceptance towards edible insects, so promotions through younger generations and future thinking has potential (Trang, 2021).
2. Mass rearing of insect populations within close proximity and in high densities is prone to disease outbreaks and the spread of pathogens (UK Centre for Ecology & Hydrology, 2022). These diseases can cause infertility and weakness in insects, leading to population decline and economic losses for producers. Stringent food safety and hygiene standards must be followed to avoid disease.
3. Insects are allergenic (can cause allergic reactions for some) and fall under the allergen statement of crustaceans, which can be problematic for some consumers. However, through appropriate processing techniques, these allergens may be neutralised or reduced (De Marchi et al., 2021).
4. Property and land are scarce in Singapore, so securing a suitable location for vertical farming is critical and may be expensive. Additional capital costs may include post-harvest processing equipment such as grinders and commercial dryers.
5. There are risks associated with gathering insects from the wild, including over-exploitation leading to endangerment of the species (Van Huis & Oonincx, 2017).
6. Globally, the use and acceptability of insects as a food source is undermined by a lack of information, media, and knowledge, especially in Western countries. Many consumers have cultural perceptions of insects as dirty, unsafe, and carrying the risk of disease.
7. Discussion and transparency may be required on the ethics of insect death. Farmed insects are typically ethically euthanised with gas before processing. It will be important to ensure consumers are aware of and satisfied with this practice.
8. Under Te Tiriti o Waitangi, the commercialisation and export of products involving native species may be limited. To ensure cultural considerations and Te Tiriti principles are upheld, it will be important for researchers to involve relevant tangata whenua, mana whenua, iwi, and hapū in the R&D process. Consultation with these groups is especially important if the insects are native to New Zealand.

Regulatory environment

Trade and biosecurity

Insects are a new food source in Singapore, unlike other Southeast Asian countries such as Vietnam, Cambodia, and Thailand, which have a history of consuming insects. As of 2021, both live and deceased insects are not permitted as food products in Singapore (Morrison & Foerster LLP et al., n.d.). However, challenges from two edible insect start-ups, Asia Insect Farm Solution (AIFS) and Altimate Nutrition, have led to exemptions being considered (Trang, 2021).

According to Section 5 of the Imports and Exports (Living Modified Organisms) Prohibition Order 2005 (Cartwright, 2005), in order for insects to be exported out of New Zealand to help people with Type 2 diabetes, insects that are genetically modified to help express genes may be exported if they have pharmaceutical capabilities. Furthermore, they are required to meet Section 7 (Cartwright, 2005), which states that they are able to be exported if handled and transported under safe and relevant conditions following New Zealand and international rules. The export of any living organism out of New Zealand will also require documentation under New Zealand protocols (Cartwright, 2005).

To adhere to Singapore regulations, the Singapore Animal and Veterinary Service will need to approve the imported product (Animal & Veterinary Service, 2020). It needs to inspect the importation to ensure it is permitted under the CITES agreement on the Networked Trade Platform website (Singapore Customs, n.d.).

Food safety and quality assurance

Singapore has strict food safety and biosecurity standards that require insects that are imported into Singapore to be free of disease contamination.

The quality of the product is monitored through various testing methods to ensure production meets the high food standards. The import and export of insects between New Zealand and Singapore is a significant quality control point, and no biosecurity risks or contamination must be transferred during this process. Multiple testing rounds and isolation of the bred insects should be considered, so they will meet and surpass exporting laws set by MPI (New Zealand Ministry of Primary Industries, n.d.).

Initial quality control and product standards completed in New Zealand will be supported through the correct documentation supplied from MPI, prior to export. This ensures live insects (crickets) meet the standards and regulations required to enter Singapore under their strict importing laws. Crickets are classed as an agricultural pest in Singapore, so correct procedures must be followed during their importation (Animal & Veterinary Service, 2020).

Food manufactured in Singapore must meet the national standards and regulations for machinery, insects, and processing. These include regular audits, Hazard Analysis of Critical Control Points (HACCP), Safety Operating Procedures (SOPs), foreign matter checks, as well as metal detection and pathogenic bacteria checks and regular nutritional composition testing. Adequate food safety checks are particularly important in insect farming to ensure frass and exuviae are separated sufficiently before processing occurs.

Conclusion

This report suggests a strong opportunity for New Zealand and Singapore to partner in a joint venture to breed a superior cricket species for vertical farming and consumption in Singapore. Vertical insect farming will help Singapore achieve its '30 by 30' goal, while maintaining sustainable practices. This high-value product will provide Singapore with an alternative innovative protein and nutritionally dense source of micronutrients.

New Zealand is well-placed to develop a suitable cricket breed, because of its extensive experience in agriscience and R&D capabilities. The relationship between New Zealand and Singapore is strong, and more integration and sharing of knowledge between the two countries will further help the development of insect breeding capabilities.

The proposed concept was chosen for its circular sustainable model, low resource requirements, and potential to reduce waste within vertical farming systems. Cricket waste can be used to create another high-value fertiliser product to help vegetable vertical farms.

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