Chapter 1

Introduction to food disruptions

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1.1 Introduction

The agri-food sector is one of the largest manufacturing sectors globally and comprises a dynamic societal-technical innovation ecosystem (Rowan, 2019; Saguy, Roos, & Cohen, 2018). In the EU, this increasingly important sector accounts for €1098 billion turnovers and employs 4.24 million (Saguy et al., 2018). Over the last decade, the food and beverage industry has doubled in size in the USA (Rowan and Galanakis, 2020). The food and drink industry was estimated to be worth £6 trillion in 2015, with packaging comprising almost £1.9 trillion of this value, where digital innovation is rapidly influencing the pace and scale of change (Rowan and Galanakis, 2020). Food manufacturers invested ca. $18 billion in capital expenditures in 2016 (Rowan and Galanakis, 2020). There is an increasing demand for the supply of safe, nutritious food that echoes future projections that support global population growth (Michelini, Principato, & Iseavoli, 2018; Rowan and Galanakis, 2020). The aforementioned brings challenges and opportunities where diversification of the food supply chain will meet altering diets that respond to increasingly aging, ethnic and cultural populations, diet-related diseases, more personalized products, and the possible emergence of innovations and services to address void created by coronavirus disease (COVID-19) pandemic. The global COVID-19 pandemic has produced a paradigm shift for society, and the food industry is meeting this challenge. However, it will also slow economic recovery or occurrence of the second wave of infection will create additional opportunities for innovators and services such as online retail and deliveries (Rowan & Laffey, 2020). DBEI (2018a, 2018b) projects that there will be a ca. 70% rise in demand for more food products and services over the next 40 years.

Opportunities will be met in part by advances in the digitization of food technologies, processes, and services for a diversity of markets along with commensurate sustaining and disruptive innovation in the adjacent manufacturing and materials sectors. In the years ahead, it is envisaged that organic, unprocessed, and healthy food will drive growth in domestic markets (Statista, 2020). For example, the estimated value of shipments of the indus-

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try was US$ 795.4 billion in 2019, where. 15.1% of the value of shipments was generated from dairy product manufacturing. Exploiting added-value from premium dairy products has led to the establishment of the dedicated VistaMilk Center in the Republic of Ireland that combines Agri-Food with information communications technology (ICT) research institutes along with prominent companies. VistaMilk Center is funded by Irish Department of Agriculture Food and the Marine (DAFM) and Science Foundation Ireland (SFI) that will forge sustaining and disruptive innovation across animal and human health, integrated and rapid sensing, and communications for intensive sustainability, with an environmental orientation (Science Foundation Ireland, 2020).

The primary purpose of this introductory chapter is to provide a background describing advances in the agri-food sector in the context of articulating what constitutes technology disruption across this domain and potential new emergent disruptors where many activities are evident across many domains, which are addressed in the proceeding linked chapters. The overarching goal is to introduce fundamental, conceptual, and best applied-knowledge underpinning food disruptions, where a more profound and broader appreciation of how these technologies disrupt social and innovation ecosystems are seen to be adaptive and dynamic. Specifically, this also includes a high-level introduction to digital technologies in agriculture; digital disruption in the food industry; personalized nutrition and omics technologies; changes in eating habits; alternative protein sources; artificial meat; innovations in functional foods development, trends in smart packaging; 3D printing; electronic nose for food authentication; the Internet of Things (IoT). Technologies in the food supply chain; innovative distribution and delivery of food; social acceptability of food disruptions; blockchain in agriculture; digital extension service; food-drug interactions; digital technologies and personalized nutrition; food choice, personalized nutrition, and food sustainability; and IoT in the food sector. This book will also inform new education and training programs for the food industry and a variety of other stakeholders globally.

1.1.1 Challenges and opportunities presented by the need to meet food sustainability

Future intensive sustainability of the food sector will also be influenced by pressures applied to supply chain, including uncertainties associated with the impact of global warming on crops that will include more flooding and droughts (O'Neill, Rowan, & Fogarty, 2019). A higher drive to innovate will also lead to commensurate needs to balance the impact on the environment with the emergence of less-energy intensive, eco-friendly processes, products, and services (O'Neill et al., 2019). Fisheries and seafood are viewed as desirable high protein, low carbon-intensive products with the emergence of smart aquaculture processes to meet growing consumer demands (Tahar et al., 2018a; Tahar et al., 2018b; O'Neill et al., 2019). The role of predictive modeling to inform efficacy for adjacent water security is also becoming more popular (Tahar, Tiedeken, Clifford, Cummins, & Rowan, 2017, Tahar, Tiedeken, & Rowan, 2018c). However, Ruis-Salmón et al. (2020) also reported that the seafood and aquaculture sectors across European countries are embracing opportunities to mitigate key environmental pressure points (depletion of resources and climate change), social needs (changing customer attitudes and preferences) or growth in markets (services and business processes along with enhanced competition and worldwide competitiveness). These pressing challenges are influencing the innovation ecosystem from citizens to policymakers to adopt and foster more sustainable practices. There is a commensurate need to harness and accelerate a diversity of partnerships that traverses geographical boundaries in order to generate more effective and efficient networks across seafood and aquaculture sectors along the entire food supply chain. Ruis-Salmón et al. (2020) stated that such challenges and opportunities would be addressed by "a convergence of thinking" in a connected innovation ecosystem that exploits advances in life cycle assessment and modeling that will enable a sustained unite progression to a circular economy. This timely review highlighted that interfaced between food-energy and water will support the assessment of the life cycle of seafood products and services, which will include tracking trends for regional limitations and strengths. This fact will lead to the sharing of new knowledge for add value across European seafood and aquaculture sector, including innovation in ecolabeling and ecodesign that will have far-reaching and cross-cutting influences to the circular economy. Smart innovations in these areas may lead to disruptive products and businesses.

1.1.2 What are disruptive technologies?

Disruptive technologies or disruptive innovations were initially defined to address market disruption in established markets, where a new product or service (a technology) is introduced (Bower & Christensen, 1995; Christensen, Anthony, & Roth, 2004). Sequentially, over the past 20 years, several researchers have expanded upon the theories of Bower and Christensen (1995) to include low and high-end disruptions to meet convergence of new opportunities from adjacent domains (Govindarajan & Kopalle, 2006; Schuelke-Leech, 2018). DTs arise from a global drive to discover innovations that will lead to greater competitiveness, impact and value to businesses and society (Christensen & Bower, 1996; Geels, 2018; Laurer & Dgostino, 2013; Li, Porter, & Suominen, 2018; Sousa & Rocha, 2018; Yongfu et al., 2017). However, several researchers have espoused to expand upon the classic pattern of disruptive innovation identified by Clayton Christensen in 1997 over these past 2 decades, which may not be aligned with his original thinkings. Christensen recently reaffirmed his definition of disruption that is a theory of competitive response. If one innovates in a certain way, then it is envisaged that the incumbent competitors would be expected to do similarly. If one introduces a sustaining innovation, then the incumbents will typically endeavor to mount a defense with a view to eliminating me. However, if the innovation is disruptive, then one is likely to be ignored, or competitors will flee rather than mounting a fight (Denning, 2016). Denning (2016), in his recent "Christensen Updates Disruption Theory" paper, stated that "this is a theory in which an unobtrusive competitor eats away at the low end of an incumbent's market with a lower quality product. The incumbent is happy to concede the low-value customers and concentrates on adding more features for its base of high-value customers. Next, the disruptor steadily improves quality to move up-market, and then devours the whole market of the incumbent, who often does not perceive the threat until it is too late".

Since the 1990s, researchers have referred to DTs as a whirlwind, ground-breaking, game-changing, earth-quake, and emergent technologies that typically cause a substantial disturbance in established market structure and prominent companies by producing highly efficient products and services that are more competitively priced, less complicated and more accessible than established innovations (Christensen & Bower, 1996; Christensen, 1997; Schuleke-Leech, 2018). Innovations may be viewed as disruptive when they take the place of established or broadly accepted ideas arising from scientific inquiry, or in methodologies or in paradigms that causes disruption in knowledge (Kuhn, 1962). Schuelke-Leech (2018) also reminded us that disruptions could also be seen in legal and regulatory settings, such as the withdrawal of the United Kingdom as a joint member of the European Union that was commonly referred to as Brexit. DTs are seen as different from sustaining technologies (ST) that offer incremental improvements over products and services already known. However, given the potential impact of DTs on businesses and society, most new technologies are considered as sustaining (Garrison, 2009).

Schuleke-Leech (2018) recently noted that DTs have historically presented challenges to executive management by way of uncertainty and flux in appreciation and deployment of innovations framed upon a level of prior familiarity, transparency, and experiences in discerning strengths, weaknesses, opportunities, and threats for these technologies. A limiting factor in the uptake of new potential DTs may relate to poor-decision making in adopting and embracing these innovations. However, the challenges for technological forecasters and investors it that DTs are by their nature nascent, meaning that they can only be proven as disruptive in hindsight based upon demonstrating evidence-based impact. This fact infers that technology investors must have an appreciation of what constitutes technology disruption in terms of evaluating candidate innovations that have the potential for paradigm disruptive shift (i.e., DTs), as opposed to an incremental sustaining drift (i.e., STs). Review of the best evidence on this subject highlights that one can only assert "potential" as proof of efficacy for disruption for new product or service as this can only be determined proper on review of the impact on the marketplace by end-users and its utility for application across different domains. Schuleke-Leech (2008) described that new disruptions might be much more massive if they emerge from disrupting the model of capitalism, organizational structures, or social interactions, which are steps beyond transforming the marketplace or existing technological paradigm. It is evidenced by Beinhocker (2006) that predicting the type of disruption can be challenging in a complex system, such as for innovation that often have multiple and dynamic contributions.

In recent times, definitions of DT focus on broad factors affecting the industry and address the nexus between learning experience arising from substitutable innovations that relate explicitly to competitive pricing and performance (Rowan, 2019). The recent review by Beth Ann Schulke-Leech (2018) provides an excellent insight into a diversity of DTs. The author describes disruptive-products that are reduced in size, such as exploiting leading developments in nanotechnology. Those that are more lightweight and efficient, such as exploiting additive manufacturing and material science. Those that are more competitively and affordably priced, such as exploiting resource management and manufacturing, including advances in innovative service and business processes. Where other products are exhibit more excellent dexterity and convenience in design and functionality that includes exploiting researcher creativity blended with artificial intelligence, augmented, and virtual reality that includes future-proofing for needs across various platforms. In addition, products that are more significant performing products and services, such as exploiting Physico-chemical developments combined with the use of robotics and AI for design linked to advances in education and workforce training). For example, this author's research group presented for the first time at Kilmer Sterilization Conference on the combined novel use of educational and immersive (augmented and virtual reality) technologies to inform remote workforce training for adjacent medical technology and terminal sterilization industry; this has disruptive potential, but only over time will this be proven (Murray, Buckley, Seery, & Rowan, 2019). Similarly, this concept may be applied to the food industry for the introduction and training of new technologies across the supply chain from production, distribution, and storage. Developing DTs in the agri-food domain is core to supporting and driving national strategic development plans as these generate the job, add-value, troubleshoot, and enhance quality in changing marketplaces. Schuekle-Leech (2018) provided an excellent review of the factors that underpin why potentially do localized technological innovations lead to much more significant technological disruptions, which cause a larger society where the more significant longer-term impact occurs. Rowan (2019) recently reviewed the development and potentially disruptive technological potential of pulsed light technology for the food and adjacent industries where he reviewed vital factors and potential magnitude of disruption.

Christensen previously explained that disruptive innovation influenced by three theories. The first is the "Disruption Innovation Theory," where organizations use simple, convenient, cost-effective innovations. The second is the "Resources, Processes, and Values (RPV) theory," where these composite theories frame a company's strengths and weaknesses. The third is the "Value Chain Evolution Theory," where a company requires to control its value chain and solve problems that, if not addressed, would inhibit it from harnessing value from these critical activities) (Christensen et al., 2004). Other scholars have pursued the expansion of Christensen's definition of disruptive technologies, which includes potentially broadening these to include both high and low-end disruptions (Govindarajan & Kopalle, 2006) and potentially distinguishing between disruptive technology and disruptive innovation (Yu and Hang, 2010). Shuekele-Leech (2018) stated that this presents challenges in defining what constitutes technology disruption as there are several levels of disruption. However, as stated previously, these may not be aligned with the original thinking of Clayton Christensen. Denning (2016) reported that Christensen feels that the core concept of the disruption theory has been broadly misunderstood and misapplied due to the success that it has garnered for the past 2 decades, as attested in part by highly effective use of these theories by leading companies and institutions. The theory of disruption, according to Christensen, "is a theory of competitive response. Disruption is a process, not an event, and innovations can only be disruptive relative to something else. Over the last 20 years, little by little, we have realized that we need new theories to account for what is going on." (Denning, 2016). This author reports that Christensen recognizes the existence of multiple patterns of disruptions in today's marketplace. Christensen explained that three types of innovations play different roles in the economy, namely (1) market-creating innovation plays a role in growth (2), sustaining innovations make right products better, and (3), which was not recognized in original thinking of 1997 that the role of efficiency innovations eliminate jobs.

1.1.3 Orders of magnitude for disruptive technologies

In the exciting work of Schuelke-Leech (2018), Beth Ann described a conceptual model to understand the orders of magnitude of DTs that may disrupt markets, businesses, institutions, and the societal norm, which constitute "the innovation ecosystem." Specifically, such disruptions occur at two different levels. Technologies or innovations that constitute disruption at first order reflects a localized change in a given marketplace or industry sector that aligns with Christensen's conceptualization of disruptive technology. Schuleke-Leech (2018) gave an example of Keurig K-cup single-serve coffee machine (the single-serve plastic coffee pod) as the first-order disruption where 9.8 billion individual coffee pods where sold in 2014 . First order-level disruption is the focus of much the business literature where it considers and addresses disrupters in innovation. Schuleke-Leech (2018) postulated that if one was to that the underpinning concept of this single-serving machine and combined it with a future point with advances in 3D Printing and ICT to create on-demand meals. Then this would have much more extensive and wider-scale influences, potentially affecting many industries and dramatically altering societal norms or situation, and as such, would represent a second-order disruption. Therefore, second-order are technological disruptions that permeate through society, influencing substantial change. Another example of the first to second-order technological conversion would be the discovery of the enzyme polymerase, and it is used in polymerase chain reaction (PCR) technologies that now have disruptive seismic influences across many sectors, including food that includes diagnostic, quality assurance. PCR transforming our ability to work with sophisticated foodborne viruses and parasites in real-time that are not culturable by conventional methods and has been the go-to method for testing the COVID-19 virus in healthcare for a current pandemic. If one then considers introducing AI, AR/VR, and the Internet of Things, this combined concept could be used for valuable remote workforce training using broad throughput PCR as crucial technology that would affect service, business models, and education, which would be additional second-order disruption. For example, many international educational programs seek to provide valuable mobility for researcher training and professional development; the use of virtual remote training on core technologies would influence other order disruption in knowledge provision that currently relies upon more hands-on in situ demonstrations at a defined location (Rowan, 2019).

Second-order disruptions are broader than first-order disruptions. Described by Schuleke-Leech (2018), second-order DT (1) are not localized and are dynamic advances on existing technologies that frequently combine several separate innovations that might or might not be causing disruption at the first-order level (i.e., locally seen individually as disrupting technologies); (2) emergent innovations that are broadly applied across many different industries; (3) technologies that disrupt current social, institutional norms and standards, operation, production, trends, not limited to a particular market or industry through restructuring, and reorganizing, and (4) technologies that trigger and develop economy-wide growth similar to Kondratieff's waves. However, different second-order DTs may be combined, resulting in a Kondratieff long wave. Kondratieff identified cyclic patterns in capitalist economies in the 1920s (cited Schuleke-Leech, 2018) where others subsequently developed this concept further noting that cycles are seen as linear and sequential and come to dominate and drive economies (Freeman, Clark, & Soete, 1982; Perez, 2002; Schumpeter, 1939a, 1939b). A single dominant technology is at the center of each long wave, such as Wernher Von Braun liquid-propellant rocket engine invented during WWII that disrupted jet aviation and space exploration. Schukeke-Leech (2018) stated that while second-order disruptions are far-reaching than first-order disruptions, they are still considered smaller in influence than long waves. Advances in ICTs was provided as an example for driving long wave that came through several technological developments in hardware, telecommunications, the Internet, and networking (Ceruzzi, 1999).

First and second-order DTs are considered revolutionary technologies as opposed to innovations that lead to incremental, evolutionary, or continuous developments (Utterback, 1994). There is a great desire to understand the process whereby one can identify candidate technology disruptors (Nagji & Tuff, 2012). Schuleke-Leech (2018) noted that factors leading to the creation of DTs arise from meeting a localized opportunity (Christensen, 2003); through creativity and problem solving (Rowan, 2019); through financial investments (such as from self-financing to Venture Capital and Angel investors); (Rowan, 2019); through exploiting appropriate networks (Rowan, 2019); through considering broad applicability for an innovative technology (Schuleke-Leech, 2018); and by providing supporting infrastructure and institutions (such as clustering of human capital, networking to enable the innovative process to occur, Drucker, 1985). Governments play a central role in driving in informing the creation of DTs through investment in education along with providing economic and policy conditions enabling start-ups, innovators, or companies to take on the challenge with high-risk products and services (Streeck, 2011). The reader is encouraged to consult the informative workings of Schuleke-Leech (2018) for a comprehensive understanding of the role disruptive technologies, factors underpinning the orders of magnitude of disruption, and associated modeling of processes that provide critical insight into these innovations across several domains. Climate change, COVID-19, and other uncertain influences were affecting technology disruption.

The UN Environment Program noted that if we are to achieve the Paris Agreement goal of limiting substantial global warming to 1.5°C, then global carbon emissions must be reduced to 7.6% a year. Failure to achieve this aim by 2030 will result in irreversible impacts, including enhanced extreme weather events along with increased existential threats to humans. For example, in the Republic of Ireland, agriculture accounts for a third of carbon emissions where there is an increased interest in innovation and practices in order to help reduce annual emissions from 40 million tonnes to 19.4 million tonnes. This fact is also set against a global background where the National Centers for Environmental Information in the United States has recently reported that January 2020 was the warmest recorded over the past 141 years (NAOO, 2020). This report is also alarming given that the highest January recorded for land and ocean surface temperature internationally at 2.05°F (1.14°C) above the average reported for the 20th-century. It was noted that the past 4 years also represented the four warmest Januaries recorded in the United States;

the 10 warmest have all occurred since 2002. This trend in terms of record climate temperatures is similar, as reported by other continents such as Europe (Mullen et al., 2018). The uncertainly of climate change influences agriculture and food production as increased flooding and droughts disrupt food and water systems. Sustaining water quality and security resources will also be a challenge for future agriculture and food production processes (Tiedeken, Tahar, McHugh, & Rowan, 2017). Rowan (2019) has also described the influence of climate change on linked pollination and ecosystem service management, where pollinators are affected by habitat loss, starvation, and complex diseases. Introduction of nonthermal disruptive technologies such as electron-beam or pulsed UV light treatments may facilitate commercial decontamination of pollen for farmed bumblebees that are now cultured to help with loss of our pollinators globally (Naughton, Tiedeken, Garvey, Stout, & Rowan, 2017). The decline of bee pollinators is an alarming statistic that becomes an even more significant cause for concern when the benefits they provide to humans are weighed up, both from a nutritional and economic point of view. The pollination of crops in the USA alone is estimated to be worth more than $14 billion (cited Rowan, 2019), which is provided by honey bees (*Apis mellifera*). In Europe, 78% of all flowering plants are pollinated by animals, with 84% of crops such as strawberries, plums, cucumbers, and rapeseed oil being carried out by insects, worth 15 billion euro per year (Naughton et al., 2017). Wild bees in Ireland provide the bulk of pollination services to various crops and fruit, making them invaluable to the economy and for food variety.

There is a pressing need for smart solutions for ensuring the intensive sustainability of agriculture and food production processes that respond to the challenges of climate change. Although renewable energy deployment is increasing, fossil fuels remain the primary fuel source for heating and transportation for many countries (Schuelke-Leech, 2018), which is despite the general agreement to reduce global greenhouse gas emissions internationally (Intergovernmental Panel on Climate Change, 2019). O'Neill et al. (2019) also reported a negative correlation for the use of biomonitors of effluent quality on receiving water bodies from aquaculture production processes in the Republic of Ireland. Use of the algae produced opposite than expected ecotoxicological findings arising from a 3-month drought experience in the Republic of Ireland in 2018. Specifically, this novel study used the microalga *Pseudokirchneriella subcapitata* in the form of a new natural whole-organism biosensor to examine the conventional physicochemical parameters monitoring in aquaculture farms (namely suspended solids, oxygen, phosphorus, pH, conductivity, nitrogen, and temperature) on the receiving waters in terms of disturbances to ecosystems and organisms. This fact is quite smart, as use of the microalgae allows for cumulative and sequential stressors along with embracing longitudinal effects of exposure time, where the use of conventional physicochemical measurements are grab samples with a specific window of time, where one may experience variances in differences in representativeness for each parameter depending on nature of the method and frequency of testing. There is significant scope to use ICT for both remote and real-time integration of this approach for smart-aquaculture, such as linked to a new mobile phone app as a next-generation management tool for controlling feed rates, BOD, and effluent quality. Studies revealed that the constructed wetland system was negatively influenced by drought conditions as this natural waste remediation process was not able to treat nitrates and phosphates effectively. Therefore, these advances in using novel algal biomonitors for holistic aquaculture process performance are complementary and potentially superior to as an indicator of standard water quality parameters and will provide an early warning tool for both aquaculture process efficiency and to factor in the influence of climate change. The role of ICT, big data, and automation in smart agriculture will play lead role sustainability moving forward. Advances in bioinformatics and next-generation sequencing will also help with improvements in different microalgae used for this purpose, as well as the determination of microbial populations in the system, including the emergence of pathogens or problematic microorganisms (Naughton et al., 2020). This fact is particularly relevant as less than 5% of microorganisms are culturable on conventional agar plates from water samples (Fitzhenry, Rowan, del Rio, Cremillieux, & Clifford, 2019; Rowan, 2011; Rowan, Valdramidis, & Gómez-López, 2015). It is envisaged that there will be continued advances and potential for technology disruption in forestry and horticulture for future environmental-proofing such as the delivery of cocktail of helper microorganisms and bioactive compounds through hydrogels from adjacent manufacturing and materials industry to respond variances in climate change and resilience. This fact is likely to be informed by advances in ICT and digital technologies in agriculture and food production.

At the time of writing, the world is experiencing a coronavirus disease (COVID-19) pandemic (cited in Rowan & Laffey, 2020). Given the necessity for food globally, disruption in products and services is likely to emerge from innovations in the delivery and online retail sector as most people remain at home to prevent infection. This is on top of the pressing needs to develop innovative means to increase food production to meet growing populations internationally informed by digital technologies. This infers a focus on food security, such as blockchain and the Internet of things in the food supply chain, safety, including smart packaging, traceability, and alternative, disruptive approaches to food sources such as protein sources. There will be considerable shot-gun market research occurring to review consumer behavior, such for example, through advances in digital extension services. This is additionally increasing preferences for personalized nutrition. Also, and underappreciated, is the potential role of functional foods and nutraceuticals such as in boosting the immune system and wellbeing for tackling COVID-19 infection (Masterson et al., 2019; Carballo et al., 2019).

The coronavirus COVID-19 pandemic crisis will present both challenges and opportunities for the agri-food sector globally. The theory of antifragility (Rowan and Galanakis, 2020) relates to the observation that some things benefit and thrive from shocks, such as exposure to volatility, disorder, and stressors. Antifragility is the concept of things that get better under the conditions of stress and uncertainty. There are pros and cons to following any given method. In terms of potential global economic recovery plans post-COVID-19, and the emergence of Food DTIFs, the significant value may be placed on such things as the review of antibody testing data where it is hoped that epidemiology will show that many people were infected where this may inform a v-shaped recession with a short sharp recovery. A desirable v-shape economic recovery trend may be more likely due to a wave of online shopping and people working from home. Approximately $6.2 trillion (12.5% of retail total) is spent on food and beverage in the USA: 2015 was the year that more food was brought in than prepared in the home. COVID-19 has shocked that trend, in the US in Q2, 100bn dollars shifted from restaurants to retail space. Migration of how people shop online. Monopolies in food grocery services may arise, where smaller independent stores may struggle. In the UK, 7% of the population shop for groceries online, with 4% in the USA. However, one-third of the US population bought online during the second week of March, and half of them was their first time. Confidence must be provided to ensure continuity in the food supply chain to avoid friction in the food system. Too much friction will lead to price increases, which includes friction in labor with seasonal workers shortages. If there is a shortage, consumers pay more, yet producers get less. This is the wrong message or signal to producers as they will produce less, which will lead to more shortages. In addition to preventing shortages in the food supply chain, there is a commensurate need to addressing food waste and remediation as countries. Thus, the use of ICT for supply chain management and to understand consumer consumption patterns during a pandemic is essential.

It is uncertain as to the state with any degree of confidence what would be the specific impact caused by the global downturn (or potential recession) in the economy as it relates to specific needs and opportunities met by emergent technologies in agri-food (including ingress from adjacent industries). However, Joseph Schumpeter's trampoline theory of rebooting an economy with innovative and growth-hungry companies coming to the fore appears plausible. This also includes the likely consolidation of major industries with strong packaging and capacity for research and innovation that will potentially flourish during and post-COVID-19 when socioeconomic norms are reset, and countries quickly deploy economic recovery plans. The flexibility and adaptability of companies to meet change and adjust business models, including provision for ICT, including online delivery for supply chain, will be better placed for sustain and for potentially cause food disruption practices. Reuters recently polled over 50 economists, with some forecasting that the world economy will shrink as much as 6% in 2020 (Reuters, 2020). However, predicted extremes include 0.7% growth to average 1.2% contraction. The V-shaped economic response is the best case outcome: when a commensurate sharp recovery trend follows a growth plunge. Reuters stated that 'the April–June GDP contraction will likely be on a scale not seen for decades.

Nevertheless, fiscal and monetary stimulus, over $10 trillion, may help with an equally swift rebound (Curran, 2020). However, confidence in V-shaped economic recovery is questionable, as noted by Bulwark (2020), as one cannot dismiss a combination of a record-high global debt-to-GDP ratio and deepest worldwide economic recession observed for many decades. Bulwark (2020) infer that these risks include an undesirable return of the European sovereign debt crisis, a potentially lower long-run growth path due to a sudden shift in the Chinese economy, and waves of debt defaults in emerging markets.

The occurrences of these combined risks may influence the occurrence of a COVID-19-induced recession. Reuters (2020) described that an alternative U-shaped economic recovery might occur, that takes more than a couple of quarters as economies have suffered a faster and deeper, which Reuters feel may be the likeliest outcome. This reflects thinking that lockdown impact may last for a while after their lifting with a gradual easing of the lockdown where social distancing will continue that will continue to influence the tourist industry negatively. This also reflects the situation where there is still no vaccine in play, and therefore, impossible to role out second waves of infection that add to uncertain (Rowan & Laffey, 2020). Reuters (2020) noted other type recovery trends, including W-shaped Double-dip seen where easing of lockdown restrictions initially, boosts activity but effects of unemployment and corporate bankruptcies then start to filter through, and this may occur if there is a second wave of infection. Also, an L-shaped recovery may occur if growth plunges and does not recover for some time. This reflects continued increasing cases of COVID-19 forcing long-term lockdowns. At the time of writing, it is too early to state with any degree of confidence what will be likely shape of economic recovery, but sustaining development and disruption in agri-food innovation, products, and services would help facilitate this recovery process globally.

Ireland, as a nation, has worked very hard to become a leader in food production, as attested by the premium quality and affordable pricing. However, in response to COVID-19, countries may consider nationalizing their supply chains for greater control to avoid reliance on another country. This has led to export bans. Nevertheless, global trade feeds one-third of the world, and producing locally means buying less and the need for more land. COVID-19 may cause a contraction in the extension of the supply chain, and countries will trade with whom they can trust. The question of relative advantage arises;

will countries afford to produce things they are not familiar with or can do, or will this be a necessity arising from potential supply chain shortage issues, for example, Personal and Protection Equipment (Rowan & Laffey, 2020)? There is likely to be an increased demand for ICT, including areas such as robotics, blockchain, algorithms to improve processes, efficiency, and sustain or create more jobs. Everyone is experiencing shock at the same time as a consequence of stay-at-home and social distancing policies, yet some people are more affected than others. The agri-food ecosystem is well-positioned to respond as it is very well defined as a platform. Where next disruptive technology emerges to meet needs of COVID-19 has yet to be determined as this situation is rapidly evolving, but strong candidate DT likely to emerge from ICT and innovations in service and business processes for the food sector such as delivery for the supply chain. Industries will need to adapt in real-time, which is challenging, given very little market data available to underpin critical decisions. Galankis (2020) recently highlighted the important position that ensuring security and safety will play in responding to challenges of COVID-19, including future provision for introducing in industry 4.0 tools to mitigate food waste along with potential opportunities to fortifying foods with ingredients to help boost consumer immunity. DTs may emerge from entrepreneurs, start-ups, SMEs, and large companies where there is growth-hunger to develop new innovations and business models radically to address COVID-19 needs. Trampoline theory of recovery is likely to help reset economies after COVID-19 pandemic that create new opportunities for food disruptive innovations in service and business processes, which may see a drive for consolidation in various industries.

1.1.4 Strategic funding initiatives to identify and accelerate DTs, a case study from the republic of Ireland

Many countries have strategically focused on providing funding initiatives merging academia and industry to identify the next disruptive technology. The Republic of Ireland launched the Enterprise–Ireland Disruptive Technology Innovation Fund (DTIF) in 2018. This is a €500 million DTIF initiative established under Project Ireland 2040 (https://dbei.gov.ie/DTIF) over the 10 years from 2018 to 2027 alongside enterprise cofunding. All questions and responses are available on this host website. These DTIF awards were to align with the Republic of Ireland's refreshed strategic priority areas for research and innovation to 2023 with a view of enhancing job creation. The DTIF Fund is aligned with the Irish Government's Future Jobs Ireland framework with a focus on "Embracing Innovation and Technological Change," where there is an emphasis on creating and advancing technology disruption on a commercial footing. This model will also facilitate uncertainties created by COVID-19 and by the need to respond to climate change in terms of the intensive sustainability of the agri-food sector in Ireland. As such, this presents a fitting example to demonstrate how a developed country strategically uses its resources to support and forge an ecosystem of creativity to facilitate the generation of new disruptive innovation. Therefore, this Irish DTIF initiative potentially represents one of the first funds of its type in the world to support, review, and fund emergent disruptive technologies where the underpinning aim is to advance the Irish knowledge and socioeconomic landscape and to grow employment. It is envisaged that pursuit of these strategic domains, and harnessing the potential of DTIFS emerging from these cross-cutting areas will also support national economic recovery plan. At the time of writing, Ireland's seasonally adjusted unemployment rate has increased to 5.4% due to the lockdown of the nation where only essential services are authorized to operate, which includes food production and supply chain. The unemployment rate in the Republic of Ireland could reach 17% with broad-spectrum imposed closure of many businesses; it is likely that many businesses may not recover and that new opportunities will present for innovators and companies during and post COVID-19.

The DTIF funding initiative in Ireland is resourced to €65m up to 2022 for projects across many thematic domains encompassing emergent preferences for advancing medical devices, ICT, artificial intelligence, blockchain, robotics, nutraceuticals, therapeutics, manufacturing and environmental. Many of the topics embedded in these DTIF funded projects feature strongly in the majority of insightful chapters described in this "Food Disruptive Technology" book. A review of current spend from the Irish Government on this DTIF initiative to date reveals a commitment of €144 million on 43 projects with 159 project partners, with many leads by start-ups and SMEs. These are typically 3-year funding awards. Analysis of the data provided shows that increased funding for this critical initiative in the priority areas Innovations in Services and Business Processing (1 project, €3.9m (2.7%)); Food (3 projects from DTIF 2, €5.2m (3.6%)); Energy, Climate Action and Sustainability (6 projects, €8.3m (5.6%); Manufacturing and Materials – Advanced and Additive Manufacturing (3 projects, €8.7m (6.0%); ICT (11 projects,€31.1m (21.6%)), and Health and Wellbeing, including Medical Devices, Diagnostics, and Therapeutics (21 projects at €86.8m (60.3%) (Figs. 1.1 and 1.2). These domains reflect the Republic of Ireland's priority strategic areas of research and innovation to 2023. Factors underpinning funding successes in different domains across the priority domains are multivariate but aligns best with meeting the criteria sought for the award along with matching strong feedback from international peer review. Fig. 1.1 describes the number of DTIF project awards in the various domains, including Food for this Republic of Ireland government initiative, since its launch in 2018. However, it is appreciated that distribution of funding award to date reflects in part the presence of global Medtech and ICT industries in Ireland, in addition to the crucial partnership with leading academic institutions, Science Foundation Ireland-funded Research Centers and Enterprise–Ireland Technology Gateways that all support MNC,

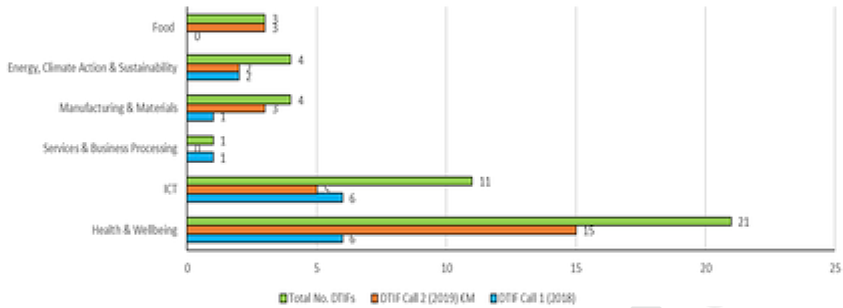

FIGURE 1.1 Number of funded projects awarded per topic in 2018 and 2019 by the Irish Government under the Disruptive Technology Innovation Fund (DTIF).

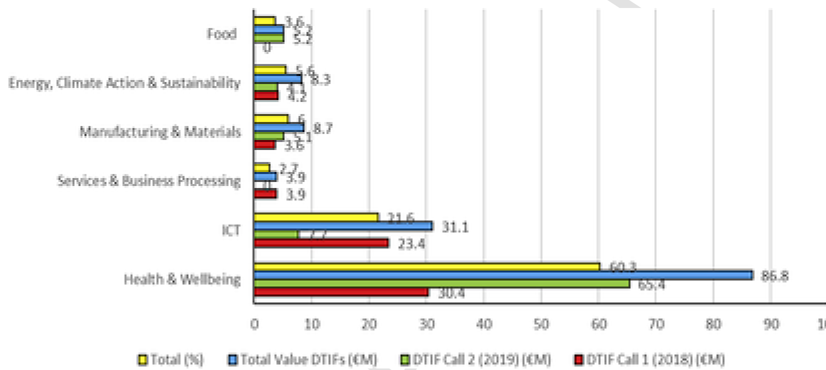

FIGURE 1.2 Amount in Euro of funded projects awarded per topic in 2018 and 2019 by the Irish Government under Disruptive Technology Innovation Fund (DTIF). Proportional representation for each topic in overall DTIF funding is shown as a percentage.

SMEs, start-ups, and entrepreneurs in a closely-knit innovation ecosystem. DTIF Call 2 (2019) initiative focused on evaluating how technology-based disruptive innovation was articulated, including collaborations that can alter markets, alter business models, and rationale for developing potentially new disruptive products and services. The initiative paid particular attention to projects of scale with a robust enterprise agenda to harness maximum medium-term economic impact for Ireland. Ideally, it sought enterprise-driven research and development challenges that could demonstrate economic impacts within 3–5 years of project completion.

The three Food DTIF successes (3/43 projects, 3.6%) emerged post review of the second call in 2019 focused on converging technologies across nutraceuticals and traceability (next-generation approaches to advancing sustainability in aquaculture); plant-based proteinaceous ingredients for exploitation as a source of high-quality protein; and beyond food labeling, authentication and certification systems (Table 1.1). However, a top-down review of Ireland's 43 DTIF funded project across all awards reveals the potential for cross-cutting relevance for a number of these platform DTIFs from adjacent domains to potentially increasingly sustain or disrupt agri-food industry, including the three stand-alone food DTIF-specific projects funded under call 2.

This initial low number (3/43) of stand-alone Food DTIF projects in Ireland relative to other priority domains, such as health and wellbeing and ICT, reflects in part the significant presence of global multinationals (such as medical devices, ICT) and drive to innovate in these areas that have high-added-value products and services. However, this needs context, as the agriculture-food industry is renowned worldwide for producing and exporting premium high-valued food products along with leading innovation. The agri-food sector in Ireland supports ca. 173,000 jobs that constitute ca. 7.7% of the total employment. Primary production in Ireland is represented by agriculture, fisheries and forestry (includes food, drink, and horticulture), which accounts for 10% of total exports worth €13bn reaching 180 markets worldwide. Cen-

TABLE 1.1 Description of awards in the Food domain under Republic of Irelands' Disruptive Technology Innovation Fund (DTIF) initiative.

Title	Project summary	Consortium
HYDRO-fish: Combining targeted nutraceuticals and traceability technology for a smarter and sustainable Irish fish aquaculture industry	HYDRO-fish is a multidisciplinary research program, specifically designed to employ current technologies from other sectors to disrupt and enhance current fish farming practices. The project entails reinforcing the supply chain of Irish salmon production, in particular for organic salmon farming.	National University of Ireland galway, Bio-marine ingredients Ireland, teagasc, marine institute
Optimised commercial-scale cultivation of protein-rich biomass from *Palmaria palmata* for the generation of health-enhancing plant-based proteinaceous ingredients.	This project aims to sustainably generate plant-based proteinaceous ingredients for exploitation as a source of high-quality protein and contribute to meeting the growing global demand for plant-based proteinaceous ingredients for animal and human consumption.	Allihies seafood, carbery, University of limerick
Beyond food labeling	Using massively multiplexed next-generation sequencing to provide a crypto-anchor for food authentication and as a substitute for costly, error-prone labeling and certification systems	IdentiGEN, University College dublin

tral Statistics Office data reveals that Irish food and drink accounts for 21% of all industrial turnover and 23% of all manufacturing industry turnover. Approximately 80% of Ireland's agricultural land is devoted to grasslands, which makes it highly suitable for food production. Key activities include: dairy products and ingredients (34%), meat and livestock (30%), prepared consumer foods (18%), beverages (11%), seafood (2%), and horticulture (2%) (Bord Bia, 2020). The innovation ecosystem is such that many of the leading food companies such as Diageo, Kerry Group, and Glanbia also are key collaborating partners in national research and innovation centers, enterprise-technology gateways, and benchmarking academic institutions that are focused sustaining and food disruption. For example, the Applied Polymer Technology Center in Athlone Institute of Technology supports ca. 300 projects per year with different start-ups, SMEs, MNCs nationally with cross-cutting links to the agri-food sector, including smart packaging, 3D printing, and nutraceuticals in terms of smart delivery systems. From a review of 143 DTIF awards in Ireland from 2018 to 2019, disruption in the food sector will be strongly influenced by disruptions occurring in other domains that will be considered as converging, and this includes inter alia advances in smart manufacturing (including use of artificial intelligence (AIT), robotics, augmented and virtual reality (AR/VR)), ICT (including Internet of Things) and innovations in service and business processes. Also, drivers for informing future technology disruption in the agri-food domain will be influenced by needs arising from COVID-10 pandemic along with balancing environmental concerns for more eco-sustainable, climate-friendly products and services.

If one conducts a more in-depth review of the Irelands 43 DTIF projects, it becomes apparent that potentially 20 (46%) at a combined award value of €86.8m (60.2%) have cross-cutting abilities to cause second-order disruption in the food domain (Table 1.2). This would include disruptive training using wearables via wireless communication, use of cytoflow5 for exploiting benefits of nutraceuticals, 3D printing of food, disruptive feed delivery, and future use of nutraceuticals for lung health using aerosol delivery under Health and Wellbeing domain. Disruptive ICT influences on food from these listed projects include the influence of AI, AR/VR and blockchain on distribution, storage of food products and materials, security, training (wearables), and financial services and logistics. In recent times, the immersive experience of using wearables through AR/VR has also been extending to Quality of Experience (QoE) (Murray, Lee, Qiao, & Miro-Muntean, 2017). Also, there is also the emergence of potential disruption on the use of smart audio and visual devices to link between in building (such as laboratory) and the field monitoring of processes. Combined ICT with manufacturing and materials designed DTIF projects include the potential for second-order disruption in smart cost-efficient packaging. Disruption in the area of food security could be potentially achieved through the sole Innovative Services and Business Processes pro-

TABLE 1.2 DTIF Projects funded by Irish Government between 2018 and 2019 – putative relationship with second-order disruption for Food.

Title of DTIF project	Priority area of award	Potential cross-link to food (potential second-order disruptive technology)	Value of award (€M)
Disruptive gene therapy platform, replacing viruses in the treatment of genetic conditions	Health and wellbeing	Not obvious, as yet	8.4
Holistics - holistic human sensing for health, aging, and wellness	Health and wellbeing	Training, as smart wearables industry value - human-centric intelligent sensors and their wireless communications for products.	7.4
AuriGen solution for persistent atrial fibrillation	Health and wellbeing	Not obvious	5.9
'The future of colorectal cancer diagnosis and treatment: Combining tissue responsive probes, AI and machine learning for medical care	Health and wellbeing	Not obvious	5.7
Therapeutic enzymes as a treatment for sepsis and other immune disorder diseases	Health and wellbeing	Cytoflow5 had the potential for informing new innovation in food – such as nutraceuticals	5
Toward safe and effective off the shelf cellular therapy for cancer	Health and wellbeing	Not obvious.	4.3

TABLE 1.2 (*Continued*)

Title of DTIF project	Priority area of award	Potential cross-link to food (potential second-order disruptive technology)	Value of award (€M)
Photonics manufacturing pilot Line €4.1 m	ICT- manufacturing	Pilot line hub will develop packaging designs tailored to fast cost-effective packaging processes and equipment and develop and next-gen packaging equipment (including test) with reduced cycle-times.	4.1
Microfluidic gene transfection cell analysis and sorting platform (GTCASP)	Health and wellbeing	Not obvious	3.4
Cooperative energy Trading system (CENTS)	ICT	Consumers and communities will be empowered with the necessary infrastructure to generate their own electricity for artisan food production with lower carbon footprint	3.0
Nex	ICT – Internet of things	Not obvious	3.0
ARDENT II	Health and wellbeing	Not obvious.	2.8
Medical imaging Ireland	Health and wellbeing	Assess impact on new nutraceuticals for lung health (Masterson et al., 2019).	2.2

TABLE 1.2 (*Continued*)

Title of DTIF project	Priority area of award	Potential cross-link to food (potential second-order disruptive technology)	Value of award (€M)
ArtEngine 2.0 bridging automated, AI-Driven 3D world creation to market	ICT – ai/ar/vr	Food 3D printing using AI as tool creation of 3D models – cost of 3D content creation is prohibitive for small studios and enables codevelopment and adoption of AR/VR.	2.0
BioHealx	Health and wellbeing	Not obvious	1.9
Sustainable Bio-renewable energy from wastewater (S-BREW) for the food and drink wastewater sector that will reduce land-spread waste and produce high-quality renewable energy.	Energy, Climate action and sustainability	Food waste reprocessing	1.8
E-BAMBI - enhanced biocompatibility of additively manufactured Biomedical implants for improved clinical outcomes	Health and wellbeing – Medical devices	Not obvious – but 3D printing focused	1.9
High throughput microfluidic drug screening platform	Health and wellbeing – Diagnostics/Therapeutics	Response models for drug testing – may have cross-link to nutraceuticals (GRAS)	1.9

TABLE 1.2 (*Continued*)

Title of DTIF project	Priority area of award	Potential cross-link to food (potential second-order disruptive technology)	Value of award (€M)
Future software systems architectures	ICT – IoT, AI,	Future use to rapidly operationalize new software systems that are slow – with AI	1.6
Irish lasers for the internet of the future (iLife)	ICT – Future networks	Not obvious, as yet	1.6
Connected medical device cybersecurity transparency	ICT – AI, data analytics - blockchain	Possible use of AI, data analytics, blockchain for real-time platform for 2-way communication of safety-critical security information (vulnerability) across food chain	1.5
Creating the bionic many – neural training suit for semimotor impairments	Health and wellbeing	Not obvious	1.5
Advanced environmental decision support system for coastal areas	Energy, climate action and sustainability	Not obvious	1.1
Smart-cardio – a paradigm shift in cardiac arrhythmia treatment	Health and wellbeing – Medical devices	Not obvious	1.1
DEFINE- AM – Disruptive finishing using electrochemical machining for additive manufacturing	Manufacturing and materials	Future link to food for challenges of post processing 3D-printed metallic parts	1.0

TABLE 1.2 (*Continued*)

Title of DTIF project	Priority area of award	Potential cross-link to food (potential second-order disruptive technology)	Value of award (€M)
Blockchain in technology product supply chain	ICT - blockchain	Food technology product supply chain	1.0
Developing inhaled bioengineered exosome therapeutics	Health and wellbeing	Delivery of smart nutraceuticals via tailored aerosol delivery technology	9.4
Qunatum computing – a software platform for multiple qubit technologies	ICT	Possible role in financial services and logistics supporting food industry	7.3
Point-of-care iron stores/ Ferritin testing for at risk blood donors	Health and wellbeing	Not obvious	7.0
Data-center audio/visual intelligence on-device	ICT	Possible role between in lab and field work for audio and vision-data on devices	6.9
Pharam latch -	Health and wellbeing	Not obvious	4.4
Stroke-CIS	Health and wellbeing	Not obvious	4.4
Blockchain and AI-Enabled stratified trial system	Innovations in service, business processes	Food security – ensuring complete (GDPR) trustworthy, control, and ownership of data	3.9

TABLE 1.2 (*Continued*)

Title of DTIF project	Priority area of award	Potential cross-link to food (potential second-order disruptive technology)	Value of award (€M)
FreeSpace project -	ICT	Wireless connectivity with ultra-high capacity wireless laser communication technology for broad food industry – delivers combination of bandwidth, availability and distance	3.6
Transfer print technology for heterogeneous integration of components	Manufacturing and materials	Possibly in food packaging	3.6
EyeVU	Health and wellbeing	Not obvious	3.2
Next-generation heat pump for affordable decarbonization of heating	Energy, climate action, sustainability	Possible role in food distribution and storage as zero carbon-emission, refrigerant-free, heat pump	2.4
Haemodialysis outcomes and patient empowerment	ICT	Possible role of AI enable software and wearable device for chronic diseases	2.1
Connected enteral feeding healthcare system	Health and wellbeing	New innovative feed delivery device design, connective and apps (possibly COVID-19)	2.0

TABLE 1.2 (*Continued*)

Title of DTIF project	Priority area of award	Potential cross-link to food (potential second-order disruptive technology)	Value of award (€M)
TRANSPIRE – a trained AI platform for regulation	ICT	Combines human and AI to demystify laws and regulations making it easier to do business while protecting consumers	2
Video intelligent search platform (VISP)	ICT	Not obvious	1.5

ject (Table 1.2). Besides, disruption may be potentially achieved in food distribution and storage through the Energy, Climate Action, and Sustainability project for reveals the use of a new zero-carbon emission, refrigerator-free, heat pump.

Identifying expert technology translators at the interface between research (academia), and enterprise (industry) to push along disruptive products and services along with connecting complementary innovators will be important for evolving the societal-technical ecosystem. Defining optimized business operational structures to harness and sustain disruptive innovation that includes leveraging immediately accessible funds to ensure cash flow and working capital is critical such as for start-ups will also be important. Traditional sources of funding through research is paid post completion of activities and reporting that would present cash flow problems, which may become more challenging to resource post-COVID-19 recovery. This has been exemplified by EU funded instruments, including Horizon 2020 that includes Future Emerging Technologies (FET) and Interreg programs that focus on regional cohesiveness. Nationally, specific enterprise or state bodies play a pivotal role in supporting innovation and facilitating the emergence of DTIFs. For example, the EU Interreg Atlantic Area Sharebiotech project investigated life science activities for identifying technology core facilities that successfully connect leading academic institutions with SEMs to information technology and business disruption. Many countries now strategically centrally resource through specialist funded centers to support increasingly sustaining and disruptive technologies. In Ireland, this is met jointly by Science Foundation Ireland's funded centers and Enterprise–Ireland's Technology Gateways. Leading scientists and engineers come together through the umbrella of Science Foundation Ireland (SFI) Research Center platforms that harness partnerships with industry and academic institutions, to innovate in order to address complex societal-technical challenges with a view to disruption (https://www.sfi.ie/sfi-research-centres/). For example, the new SFI-funded VistaMilk center combines cutting edge research and innovation for agri-food that partners leading Irish/multinational food and ICT companies. This is represented by converging renowned global expertise of the Tyndall National Institute for biosensors, Ireland's national microelectronics institute, the Insight Center for Data Analytics and the Telecommunications Software and Systems Group (TSSG) at Waterford Institute of Technology that lead have a strong reputation of leading large consortia research in similar topics supported through European funding. VistaMilk will support and accelerate next-generation innovation and decision-support-management tools to optimize efficacy across the production chain for the dairy industry. Whereas, the new Irish APC (Microbiome) SFI-funded Research Center provides another example of convergence for food disruption as it exploits microbial "microbiome" for advancing animal and human health. Key areas, including prevention and treatment of disease through exploring the role of functional food ingredients and novel therapeutics across the lifespan along with disease biomarkers. This APC (Microbiome) also elucidates relevant links between microbes and diet that includes the role of immune-modulation and signaling for wellbeing. Forecasting likely occurrence of next emergent or disruptive technology is desirable as this adds significant competitive advantage and revenue stream to companies. It is not evident, as yet, as to the degree by which investors and researchers consider smart forecast models, but this is likely to accelerate over the coming years. This facility will also help offset in part the void in knowledge created by current shock to markets and businesses caused by COVID-19. An example of a useful tool cited previously by researchers for emergent technologies is the "Gartner Hype Cycle." Lajoie & Bridges (2014) reported that using the Gartner Hype Cycle potentially helps with informed decision-making, and enables an organization to assess risk. Gartner Inc.'s research is available via its analyst webinars and blogs.

1.2 Potential technology, product and business service disruptors in food for 2020 and beyond

1.2.1 Trend toward microbial and plant-based disruptive innovations, next-generation protein sources, and alternative food ingredients

In recent times, there has been increasing interest in the augmented use of microorganisms, such as yeast, microalgae, and bacteria, in the form of protein sources (Fig. 1.3). Microorganisms are commonly used in fermented prod-

FIGURE 1.3 Bioreactor culture of microalgae used in freshwater aquaculture industry in Ireland.

ucts that we are very familiar with, such as yogurts and sauerkraut. This offers a more efficient, innovative approaches to producing the same proteins that we are already familiar with (Medical ExO,2020). The demand for such alternative food ingredients has been pushed by Millennials and Generation X with changes in eating habits (Chapter 5) along with commensurate changes in personalized nutrition. From the disruption of introducing Greek yogurt to the emergence of new functional foods such as seaweeds (Mohamed, Nadia, Hafeedza, & Rahman, 2012), there has been increasing interest in food ingredients. Such things have informed a trend toward personalized nutrition. Considerable development in this space has been the recent partnership of Nestlé with Corbion. This combines exciting expertise of Corbion's microalgae innovation with Nestlé fermentation abilities that is renowned for its smart plant-based products. Another example, include Impossible Foods, who are making soy heme (typically found in soy plants) for plant-based burgers through microbial fermentation. Impossible food burger is made with soy leghemoglobin that mimics the taste of meat. Such innovations in food ingredients may also complement growing consumer demand for eco-sustainable food sources, which also reflects changing eating habits, diets, and the new role of personalized nutrition. StartUS-Insight (2020) noted that laboratory-cultured meat might provide an alternative or complementary source to actual meat where the latter requires approximately seven tons of water to produce 450 g of beef. Interestingly, the price for producing approximately 140 g of artificial meat dropped to €9,59 Euro in 2017 from a non-affordable initial costing base of €274.366. A useful trend to follow for disruption in food production and services is to monitor activities in the USA as more than a third of the world's top food and drink processing companies are headquartered there, including Unilever, Danone, Diageo, Kirin, SABMiller, Cadbury Schweppes, Heineken, and Asahi Breweries.

High protein feed for animal and human usage will prove relevant, which has been exemplified by the intensive focus on this product for intensive aquaculture production globally. Aquaculture is rapidly developing worldwide and highlights one of the fastest growth areas for the food industry (Fečkaninová, Koščová, Mudroňová, Popelka, & Toropilová, 2017; Liu, Steele, & Meng, 2017; Tahar, Kennedy, Fitzgerald, Clifford, &&;Rowan, 2018a, Tahar, Kennedy, Fitzgerald, Clifford, & Rowan, 2018b; O'Neill et al., 2019). Aquaculture is recognized to be one of the most affordable and sustainable forms of edible protein (Liu et al., 2017). As described earlier, aquaculture's pace and scale of expansion reflect a substantial increase in our worldwide population and the commensurate demand for more safe and nutritious food (Seoane, Rioboo, Herrero, & Cid, 2014). Between 1983 and 2003, worldwide fisheries production arising from capture increased to 92.6 M tonnes from 71.1M, whereas intensive aquaculture production achieved 70.2 M tonnes from a lower 6 M tonne base (Ottinger, Clauss, & Kuenzer, 2016). In 2014, aquaculture production reached 73.8 M tonnes and now accounts for ~50% of fishery products produced for human consumption (Liu et al., 2017). Fredricks, Jewell, and Survey (2015) suggest that by 2030 aquaculture will provide an estimated 62% of fish for human consumption. Therefore, fish stocks are depleting on the oceans, and there is a countermeasure push to develop sustainable aquaculture processes with a view to enhancing disruption. Hatch-Blue is an example of accelerator SME focused on investing and progressing entrepreneurs to fast-track potential disruptive technologies for the fisheries, seafood, and aquaculture sector (https://www.hatch.blue/) globally. Precisely, hatch-blue constitutes the first accelerator program for sustainable aquaculture that seeks out, develops, and nurtures start-ups for disruptive innovation. The underpinning tenet is that it firmly believes that a sustainable aquaculture industry capable of meeting global demand for food production. Hatch-blue provides an important route to capital and revenue by exploiting considerable networking with industry that includes their worldwide investment community. The author attended this Hatch-Blue program when held in Dublin in 2019 and found it to be excellent with a clear vision in fast-tracking potentially disruptive technologies in aquaculture to market.

This 1-week intensive program was strongly supported by Bord Iascaigh Mhara (BIM, Ireland's national seafood development organization), which highlights the importance of national initiatives to capitalize on trending innovation to support job creation framed upon capturing new knowledge for the food sector.

A useful exercise to follow, in terms of mapping potential disruptive technology trends in this space, is to track innovations and approaches in marine and freshwater aquaculture (Tahar et al., 2018a, 2018b). For example, the development of new fish feeds and innovations for remote and real-time use of sensors and technologies to monitor feed rates, physicochemical parameters, and fish health. However, limitations in space that would allow for expansion of existing facilities, challenges with the development of new sites due to licensing, the lack of availability of freshwater, and the ever-growing concerns associated with pollution are thought to be significant hurdles in the further expansion of traditional aquaculture systems (Badiola, Mendiola, & Bostock, 2012; O'Neill et al., 2019). Concerns about the environmental impacts of the rapid expansion of intensive aquaculture systems have also led to increased research interest in integrated multitrophic aquaculture systems or IMTA (Granada, Sousa, Lopes, & Lemos, 2016; O'Neill et al., 2019). BIM undertook a feasibility study to assess the potential use of peatlands (bogs) for sustainable aquaculture diversification. AquaMona is an example of a new concept in integrated multitrophic aquaculture (IMTA) that has the potential to disrupt the production of high-value freshwater fish. This concept, a collaboration between Bord Na Mona and BIM in the Republic of Ireland, uses cutaway peatlands to organically farm Eurasian perch and rainbow trout, which is powered by wind energy. This Aquamona process also exploits algae and duckweed as a natural process for water quality in terms of treating rearing water and waste recycling (O'Neill et al., 2019) (Fig. 1.4). Approximately 5% of Ireland consists of peatlands that are vital for biodiversity, conservation, and maintaining our natural ecosystems. This is set against a growing trend to strategically convert from brown to green innovation, where Bord Na Mona is leading the charge in new sustainable energy-efficient technologies that are exploited to drive their new businesses in the sustainable food production area, such as medicinal plants and herbs. Findings from O'Neill et al., (2019) support the use of peatlands as future locations for integrated aquaculture processes. Bord Na Mona own and manage ca 80,000 ha of peatlands in the Republic of Ireland, where there has been the transition to renewable energy along with exploiting new businesses ventures that includes the production of high-value plants and herbs that can be used for nutraceutical and health benefits linked to workforce training and education.

An example would be tapping of Birch water from trees located across 4 ha of peatlands in the Irish midlands for potential disruption in the health and wellbeing market. Bord na (2020) is developing "birchwater" that is the

FIGURE 1.4 Aerial view of 'AquaMona' peatlands freshwater aquaculture RAS process in Irish Midlands. *Picture furnished by Bord na Móna, with permission.*

sap from birch trees as it is rich in natural nutrients and low in sugar with a view to marketing as a new health-promoting beverage. Bord na Mona states that "Birchwater is an electrolyte-replacing beverage, high in antioxidants and similar to coconut or maple water." Bord na Mona has approximately 8000 ha of naturally colonized birch trees on their raised bogs and is also using birchwater as new smart ingredients for cosmetics and personal care products. The use of aquaculture model has also been exploited to investigate potentially new disruptive immune-priming nutraceuticals, such as beta-glucans from yeast, along with microalgae extracts, for fish health that has been reported to have positive implications for the gut microbiome in fish (Carballo et al., 2019).

Aquaculture has progressed toward water, and waste recirculation production models, or disruptive recirculation aquaculture system (RAS) approaches (Tahar et al., 2018a; Tahar et al., 2018b), in order to negate effluent release to environment that is important for the sustainability of the industry (O'Neill et al., 2019). These advanced production systems provide efficient, reliable, and repeatability systems for farmed fish production that includes a trend toward exploiting biomonitoring techniques such as the use of microalgae to detect pollutants or dynamic changes in processes, such as the impact of climate change (O'Neill et al., 2019). Naughton et al., (2020) has also demonstrated the potential for using flow cytometry in laboratory setting matched with in-field use of AlgaeTorch for monitoring natural microalgae diversity and populations as natural biological means of regulating water quality in aquaculture processes. The AlgaeTorch, produced by bbe Moldaenke, is a potentially disruptive technology as it enables both real-time and in-the-field measurement of microalgae and cyanobacteria in all types of water. AlgaeTorch measures chlorophyll-a of intact cells without sample preparation, where complete measurement needs less than 20 s. No sampling or preparation is necessary. The combined use of Flow-Cytometry and AlgaeTorch may disrupt natural aquaculture processes as there is less reliance on the use of energy-intensive technologies and aeration, where these innovations low-carbon emissions and waste remediation for both food sustainability and bioeconomy. However, time will tell where these approaches are seen as increasing sustaining or disruptive in nature.

1.2.2 Other innovation that will inform food disruption

Blockchain offers an exciting security-proof approach to recording every digital transaction that can inform a broad spectrum of smart innovations from business processes to 5G networks (Sharma and Singh, 2020). In the food disruption context, it has the potential to radically transform and disrupt safety and quality, waste remediation and recycling, security, and authenticity and traceability (Medical Expo, 2020). Medical Expo (2020) noted, by way of example, that a critical driver for this technology in the food space has been the deployment of IBM Food Trust of blockchain for improving food standardization and efficiencies throughout the entire supply chain.

Artificial intelligence (AI) is increasingly used to develop new foods and flavors, such as Coca Cola's research into the Cherry Stripe in 2017 (Medical Expo, 2020). AI will play a prominent role in the personalization of foods and nutrition, exploiting the vast potential of digitalization. The robotics industry is estimated to be work ca. €2.2 billion by 2022 and has to potential to transform the food industry. StarUSs-Insight (2020) noted that food and liquid processing might be advanced by exploiting robotics as this innovation can increase output, reduce cost while enhancing the quality of service along the supply chain. Interestingly, safety regulations distinguish food robotics from other automation that will inform efficiency, including using high-quality, sustainable ingredients. For example, StartUSs-Insight (2020) reported that Momentum Machines had developed a fully autonomous burger machine that can slice toppings, grill, assemble, and package the finished product without the need for using people. This innovative process also facilities personalized orders, including selecting a variety of sauces and seasonings.

There has been a global push to readdress dependency on single-use plastics with a greater focus on smart packaging, including the emergence of potential for bioplastics. Large companies such as Diago and Nestlé, are leading the way in recycling technologies, such as for multipacks for beer and bottled water, respectively. (Medical Expo, 2020). Food wastes cost the EU approximately €143 billion, where approximately 88 million tonnes are wasted annually (StartUS-Insight, 2020). Several initiatives have progressed to address waste reprocessing, for example, the creation of a dedicated National Bioeconomy Center in the Republic of Ireland to exploit waste streams for the dairy industry. This is also the subject of many transnational research and innovation initiatives such as recently funded by European Commission, Interreg Neptunus project that combines academic expertise with the industry across the Atlantic area to address waste recycling in the fisheries and seafood area, including life cycle assessment, valorization, and eco-labeling (https://neptunus-project.eu/). Also, there is increasing commitment by the takeaway service across many European countries to reduce the amount of edible food thrown away by restaurants (StartUS-Insight, 2020).

There is also increasing interest in the development of 3D printers, also known as additive manufacturing, as a sustaining and potentially disruptive technology for a wide range of possibilities for the food industry. 3D food printers also permit personalized and repeatable nutrition where it is considered to provide the correct amount of nutrients to match different lifestyles, gender, and health requirements. For example, experimental 3D Bioprinters are designed to prints living cells that have the potential to advance food supply chain needs. StartUS-Insight (2020) provided the example of Natural Machines that advance cooking with fresh ingredients. The innovative startup behind this 3D food printer is Foodini (StartUS-Insight, 2020). There is also increasing evidence as to the role of 3D printers for food products. Therefore, 3D printers can help realize the potential to produce intricate food designs that include provision for automation, such as personalized meal preparation. Brunner, Delley, and Denkel (2018) described how 3D printers provide the potential for innovation across the food manufacturing, retail, and catering sectors. However, the role of social marketing and communication to inform behavior changes and to seek feedback on attitudes, perceptions, and barriers for the uptake of this technology will be necessary, particularly as one radically informs new concepts, it is crucial to appreciate the market need for active uptake and to refine products for different opportunities (Brunner et al., 2018).

There has been increasing evidence as to the changing preferences in diets that reflect the lifestyle and emerging therapeutic needs of consumers. This coincides with the dawn of a new era of personalized nutrition, or personalized meals that are steadily informing and transforming the food industry. Tailor-diets are an exciting opportunity. Also, the preference for functional foods or nutraceuticals that boost immune-system and wellbeing for COVID-19 are likely to become famous (example, Masterson et al., 2019), as are innovative products that will help the nutritional and immunomodulatory recovery of patients postcontracting COVID-19 (Masterson et al., 2020). These products may emerge from seaweeds, yeast, algae, plants, and fungi or mushrooms that reduce inflammatory responses that are typically associated with cytokine storm in severe COVID-19 patients. The London-based Nutrifix caters for personalized diets where they recommend meals to cook, buy, or have delivered, tailored to consumers' nutritional needs.

Food delivery companies are beginning to concentrate on exploiting the role of artificial intelligence (AI) for problem-solving matches with automation, such as automated guided vehicles. As an example, slow-moving pavement droids to deliver food have been tested by Just Eat, who has partnered with Starship Technologies for this exciting opportunity. These droids are guided by a GPS signal and cameras to navigate around obstacles (StartUS-Insight, 2020). The Internet of Things (IoT) is increasingly becoming relevant for the next-generation food industry, which includes forging innovation in services and business processes. For example, the Internet introduced an innovation suitable for all kitchen devices such as analysis of items for food refrigeration, including taking note of expiration dates with provision for suggesting recipes along with meal preparation.

Additionally, the inbuilt recognition system supports consumers in keeping an eye on their fridge via smartphone or tablet (StartUS-Insight, 2020). Food security is also an essential factor to have to the fore, which includes frequent concerns over contamination of shellfish with Norovirus or the Winter-Vomiting bug. The monitoring of food from field to fork using IoT technologies presents a logical solution to this challenge that also must ensure that such innovative technologies align with food safety standards. StartUS-Insight (2020) noted that the start-up TellSpec developed a potential solution for cloud-based spectroscopy. The patented AI-based real-time cloud analysis engine helps monitor events of food fraud, as well as of food contamination, where it helps consumers and authorities to make choices to prevent the onset of health issues related to food.

1.3 Summary

Enhanced innovation leading to the creation of new disruptive technologies in the agri-food domain will inform new exciting new products and services that will address challenges and opportunities for the intensive sustainability of the industry, including embracing COVID-19 pandemic crisis. Defining and forecasting what constitutes a disruptive technology is complicated as the impact is more likely to be measured from a retrospective downstream perspective. Disruptive technologies can substantially cause localized change within a market or industry (i.e., first-order disruption) or cause ground-breaking changes across many cross-cutting domains (i.e., second-order disruption) over a relatively short or more extended time period that substantially influences societal norms. Modern-day and future disruptive technologies for the agri-food sector will be influenced by the growing demand to produce more safe, nutritious foods to meet growing populations that reflects dynamic changes in eating habits such as personalized nutrition, alternative protein sources, and attitudes toward climate change. Disruptive technologies may be smaller, lighter, more flexible and convenient products offered at a cheaper price. Exploiting advances in ICT and advanced manufacturing will inform critical areas, including security, standards and quality, and traceability along the entire food supply chain. A review of the recent 43 projects funded by the Irish government under Science Foundation Ireland's Disruptive Technology Initiatives was used to highlight trends in the innovation ecosystem and the potential for both cross-cutting and future ground-breaking disruption in the agri-food sector with global outreach and orientation. Understanding where potential food technology disruptions are likely to occur will be aided by having a holistic perspective and appreciation of the complex socio-technological innovation ecosystem. This timely book provides the best knowledge to meet these needs that will also influence education and workforce training.

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