Fixing food with a limited menu: on (digital) solutionism in the agri-food tech sector

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Julie Guthman (Corresponding author)
https://orcid.org/0000-0002-5529-0805
Department of Sociology/Community Studies Program
University of California, Santa Cruz
jguthman@ucsc.edu

Michaelanne Butler
Department of Sociology
University of California, Santa Cruz
mibutler@ucsc.edu

Abstract

Silicon Valley and its innovation center counterparts have come upon food and agriculture as the next frontier for their unique style of innovation and impact. But what exactly can the tech sector, with expertise in information and communication technologies, bring to a domain in which the biophysical materiality of soil, plants, animals and human bodies have most challenged farmers and food companies? Based on a detailed analysis of all of the companies that have pitched their products at events sponsored by the Silicon Valley-based convener, Foodbytes!, we show that a large proportion of tech-driven solutions are digital technologies transferred from other domains. These technologies at best inform decision-making on the ecological processes of food and farming, but do not provide tools to treat them, and otherwise provide business solutions not even aimed at major challenges in food and farming. Drawing on a small set of interview data, we additionally suggest that tech entrepreneurs migrate to food and agriculture because it seems purposeful, exciting, or lucrative, but sometimes lack a clear understanding of the problems they might solve with their digital technologies. In making our case about the mismatch of problem and solution, we bring into conversation recent critiques of digital solutionism with abiding concerns in agrarian political economy and critical food studies regarding the role of the biological in both challenging food production and spurring technological intervention.

Keywords: agricultural technology, food technology, appropriationism, substitutionism, techno-solutionism, Silicon Valley

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Conflict of interest
The authors declare no conflicts of interest in the conduct of this research.

Human subjects
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A decade into the 21st century, after having exhausted its potential in the clean tech sector, Silicon Valley and its innovation center counterparts came upon food and agriculture as the next domain to which they could bring their unique style of innovation. Implicated as agriculture and food are in some of the world's most pressing challenges – climate change, food insecurity, environmental sustainability, human health and animal welfare, the agri-food domain appeared particularly amenable to innovation and investment. Encumbered, moreover, with some of the most sclerotic incumbents, it also looked to be unusually ripe for disruption. And so conferences were organized, pitch events were held, networks were formed, companies were born, and agri-food tech became a distinct and investable sector.

Since those foundational days circa 2013, marked by some as when Monsanto purchased the start-up company Climate Corps for almost a billion dollars, agri-food tech has attracted substantial investment. Global data collected by AgFunder reveals the sector garnered $51.7 billion in total funding for the year 2021, representing 3,001 deals. Significantly, this figure represents an exponential acceleration of investment, increasing more than twentyfold since 2013, which recorded $2.3 billion in deals (AgFunder, 2022). Much of this funding comes from venture capital which demands that start-ups articulate impactful solutions as well as project profitability in pitches and elsewhere (Fairbairn et al., 2022; Goldstein, 2018).

By entering into this domain with aims at disruption and impact, the Silicon Valley tech sector was ostensibly rejecting a continuation of chemical-intensive, greenhouse gas-emitting, industrial food production. At the same time, it was effectively suggesting that existing alternatives such as organic, regenerative, or diversified farming, and whole food diets and traditional vegetarianism/veganism were insufficient to the task. But what exactly could the Silicon Valley ecosystem, inclusive of start-ups, venture capitalists, incubators, accelerators, and more, bring to a domain that is deeply entwined with biological processes such as reproduction, growth, disease, contamination, and decay (Fine, 1994; Goodman and Redclift, 1994), where indeed the biophysical materiality of soil, plants, animals and human bodies have most challenged farmers and food companies (FitzSimmons and Goodman, 1998; Goodman et al., 1987; Kautsky, 1988; Mann, 1990)? Notwithstanding its geographic proximity and cultural affinities with the life sciences industry, innovation in Silicon Valley in particular has long centered on computing and communications, and more recently branched into big data, artificial intelligence (AI), internet of things (IoT) and other realms of digitalization.

In this article we argue that the tech sector's fixes, largely digital, are quite limited in what they bring to the table. Digital solutions can promise more information, connection, efficiency (Prause et al., 2021) – and may indeed provide all manner of bottom-line enhancing business solutions, but they cannot directly address the sustainability, nutrition, food safety and waste problems that ostensibly animate the tech sector's foray. This is because, for better or for worse, on their own they generally do not directly intervene in the biophysical and, hence, ecological processes of food production and consumption. Put differently, at best digital solutions can diagnose and inform decision-making on how to address such processes, but they do not provide specific tools for farmers, supply chain managers, or consumers to treat problems. To be perfectly clear, we are not arguing that digital tools are immaterial or do not have biophysical impacts – they may, for example, encourage mono-cropping of farms or reductionist approaches to food safety or nutrition – only that they themselves do not alter the form or function of plants and animals and their conditions of growth. Our point, though, is not to defend treatments born of biotechnology, much less chemical technology, the latter of which has after all created many of the problems to which the tech sector is purportedly responding, but to highlight how many of the solutions being proffered cannot fully meet the problems, a point that has barely been engaged in the rich literature on digital solutions in agriculture.

Addressing a range of domains, scholars have discussed the problems of "rendering technical" (Li, 2007) or the use of "techno-solutionism," referring to the application of technological fixes to what are essentially social and political problems, in effect avoiding the social worlds from which so many problems stem (Chalmers, 2021; Huesemann and Huesemann, 2011; Marelli et al., 2022; Milan, 2020; Sarewitz and Nelson, 2008; Segal, 2017). We concur with this critique and see the agri-food tech sector as rife with techno-fixes, especially in the realm of alternative proteins (Biltekoff and Guthman, 2022; Howard et al., 2021; Metcalf, 2013; Stephens et al., 2018). In the domain of food and agriculture, actors often pursue techno-fixes in lieu of policy to address problematic production conditions, unequal distribution, or corporate power, to name a few concerns (Duncan et al., 2021; Fairbairn et al., 2022; Howard, 2016). Tech critic Morozov (2013) offers a slightly different take on the problem with solutionism, a term he popularized. He refers to the reduction of highly complex, fluid, socially imbricated, and contentious problems to narrow, simplistic solutions (p.6). This appears to be the meaning that Fielke et al. (2022) use in their call for critique of "digital' solutionism in agriculture, or likewise, Reisman (2021) who has ascribed "disaster solutionism" to denote how the ag tech sector has jumped at the COVID pandemic as both an array of market opportunities and a source of legitimacy for their technologies. However, even these critiques of solutionism are not the core focus of this article. Instead, building on an additional meaning offered by Morozov, which stresses the rendering of technological solutions that are ill-matched to the problem or for which no problem exists, we highlight the insufficiency of digital solutions to the deeply biological problems of food and farming, along with the mundanity of the majority of solutions that populate the sector, as if along for the ride. In doing so, we bring into conversation recent critiques of digital solutionism with abiding concerns in agrarian political economy and critical food studies regarding the role of the biological in both challenging food production and, hence, spurring technological intervention.

We build our case from a detailed analysis of all companies that have pitched their products at events sponsored by Foodbytes!, a Silicon-Valley based event convener that has played a significant role in defining and advancing tech-driven start-ups in food and agriculture. Through reviewing the array of products qua solutions these companies bring to the table, we show that a minority directly treat farm and food problems with innovative technologies based in the biological and material sciences. A large proportion are digital solutions drawn from the non-biological sciences. Of these digital solutions, some provide the promised diagnostics and information in the name of addressing food and farming's biggest challenges, while considerably more provide all manner of business and coordination functions, not necessarily even specific to food and farming. The remaining plurality of "solutions" are hardly that, but are effectively re-packaged versions of products already in the market that have hitched to the attention-grabbing tech sector.

To begin to make sense of the relative dearth of solutions that can meaningfully transform food and agriculture, we draw on a small set of interview data to suggest that entrepreneurs migrate to food and agriculture because it seems purposeful, exciting, and lucrative, but sometimes lack a clear understanding of the food and farming problems they might solve with their digital technologies. In light of these findings, we conclude with ruminations about the sector's potential to develop technologies that act on the biophysical realities of agriculture and food, but do so without replicating the approaches that have caused so much harm in the past.

Before proceeding to our empirical presentation, we first elaborate on the character of past innovation in agriculture and food, to establish both the centrality of bio-chemical alteration and to some extent the differing mechanisms of institutional support than those currently at play in the tech sector. Following that, we discuss precision agriculture to show how it spearheaded the tech sector's entry into these domains and ultimately digitization across food and farming. Since precision agriculture's solutions did not necessarily change bio-chemical regimes of crop management, its case offers clues about how tech sector digitalization writ large is unlikely to address food and farming's most daunting challenges.

Past solution-making in the agri-food tech sector

Agri-food tech entrepreneurs enter a domain, sometimes without full recognition, where challenges have long been addressed by technological innovation. In their classic book *From Farming to Biotechnology*, Goodman, Sorj and Wilkinson (1987) depicted two long-term trends in the development of technology around food and agriculture. The trend they named appropriationism refers to technologies that could replace and putatively improve upon processes and inputs formerly produced on the farm by producing them in factories and selling them back to farmers. Importantly, they noted that trends in appropriationism tracked to historical shifts in technological innovation writ large, from mechanical technologies to replace labor, to chemical technologies to control pests, to biological innovation both to enhance yield and control pests. By acting on plant and animal *biologies,* appropriationist technologies would reduce risk from pests, diseases, weather and other vagaries of nature on the farm. The other trend they called substitutionism. Here the authors broadly referred to the increase in value added by post-harvest processing, yet more pointedly to the shifting of aspects of rural production to factories, allowed by the production of cheaper or industrially produced raw materials. Here the trends they tracked went from preserving (canning, refrigeration) to imitating (margarine) to synthetic substitutes (but mainly in textiles and industrial materials, not food) to, quite presciently, the kind of food engineering we are seeing today: molecular food fabrication and cellular technologies almost completely attenuated from rural production. (They did note, contra some of the claims circulating within the tech sector, that rural production would continue to provide key inputs). Crucially, by acting on the biology of food, substitutionism, like appropriationism, would make food production more controllable and predictable, as well as cheaper and nominally more appealing.

Goodman et al. did not write much about who developed these technologies and how they were financed. In the US the source of this innovation has largely come from university research in the agricultural schools and food science departments of land grant institutions – a model of agricultural research that has been replicated in other countries. For better or worse, these institutions were well equipped to integrate scientific knowledge on biology and chemistry, and to some extent mechanical engineering, and apply them to food and farming (Kirkendall, 1986; McDowell, 2001). Of course agriculture and food technology has never been the sole province of the land grant system. Private agricultural input suppliers, food manufacturers, and product distributors conducted their own research - and extension, as well. Since the 1990s, in fact, university scientists have increasingly aligned with corporations as support for public sector research and extension has declined (Busch et al., 1991; Glenna et al., 2007; McDowell, 2001; Rudy et al., 2007; Wolf and Buttel, 1996). Opportunities of appropriationism and substitutionism, along with these alignments and the abandonment of anti-trust law, left a set of highly consolidated incumbents: the likes of John Deere, Pioneer Hybrid, BASF, and others on the appropriation end and Cargill, Unilever, Tyson and more on the subsitutionism end (Howard, 2016). Notably, these are the kind of companies that tech start-ups allegedly seek to disrupt.

These start-ups also claim to disrupt the kind of problems that appropriationism and substitutionism have produced. While many farming technologies were sold as solutions to the risk and variability associated with biological production, such solutions have since become problems (Guthman, 2019; Landecker, 2015). Appropriationism led to crowded, inhumane conditions, high antibiotic use, and extensive waste in intensive livestock production and ample use of pesticides, herbicides, synthetic fertilizers and other deleterious inputs in crop production – which in various combinations contributed to the human health, animal welfare and environmental problems that animate current innovation. And while past farm technologies also promised to address farmer profitability by way of productivity, efficiency, and risk minimization, these technologies contributed to a "technology treadmill" and its attendant downward pressure on farm gate prices, as more farmers adopted productivity-enhancing technologies (Buttel and Busch, 1988; Cochrane, 1979). In confronting the problems of farming, university research and extension services, in the business of what Henke (2008) calls "repair," were not well suited to do much beyond further enhancing productivity and were certainly ill-equipped to address the social issues of farming such as labor strife. It is not until quite recently that such public institutions have tried to introduce technologies that address the problematic externalities of prior innovations, but they do so with fewer resources and more competition from other sectors (Wolf and Buttel, 1996).

Less has been written on the role of university food sciences and their relation with industry on the substitutionism side, where innovation in food generally takes place. Regardless, food manufacturers have long been in the business of reformulating food to make it more attractive and less perishable, while at the same time lowering their own production costs and shoring up market share (Levenstein, 1993; Nestle, 2002). Yet these same innovations have also contributed to low nutritional values and health-impairing additives, as well as occasional contamination. And so, as with agriculture, more recent innovations respond to the problems they created by re-engineering formulations that are allegedly more nutritious, "natural" or functional (Scrinis, 2016; Scrinis and Monteiro, 2018). In short, both appropriationism and solutionism, a project of university scientists together with food and farm business incumbents, have created many of the problems for which the food system is now vilified and in need of repair. The question, then, is whether the offerings emanating from the Silicon Valley style tech sector are up to the task.

A new kind of solution – and a new kind of problem

Enter precision agriculture, which has effectively served as the gateway to the tech sector's involvement in agri-food systems, offering both new solutions and new institutional configurations. Precision agriculture technologies, referring to a range of digital tools such as sensors and drones that can monitor field specific conditions and provide information, first came on the scene in the early 1990s. While initially marketed to improve farmer yield, in keeping with notions of repair they were soon reframed to address environmental concerns (Bronson, 2019; Duncan et al., 2021; Gugganig and Bronson, 2022; Lioutas and Charatsari, 2020; Wolf and Wood, 1997). Precision agriculture brought something different to the table than biological and chemical control: information itself. This was a trend first identified by Wolf and Buttel (1996) who noted that information was being explicitly identified as a source of competitive advantage and therefore increasingly being internalized by firms (p. 1270). They also note that precision agriculture arrived at a time of decreased support for public agricultural research and extension, implying that it was private sector firms that first introduced some of these technologies. Since precision agriculture was first introduced, the ambit of digital technologies has greatly expanded through, for example, the advent of "big data" analytics that aggregate information across sectors and geographies (Sonka and Cheng, 2015). Yet what such tools can offer remain consistent: information, coordination, efficiency.

It is important to emphasize just how different digital technologies in farming are from chemical and biological controls. The value proposition of precision agriculture is that more data about the complex, unwieldy, and risky ecosystem factors inherent to food provisioning can improve management of biophysical systems. In particular, it can allow more targeted treatments to reduce use of precious resources and toxic inputs (Bronson and Knezevic, 2016; Prause et al., 2021; Visser et al., 2021). In amassing large amounts of data beyond human senses, knowledge-based platforms presumably enhance farmer decision-making. Still, precision agriculture technologies do not directly intervene in the farm ecosystem by altering the form or function of plants and animals and their conditions of growth, but instead provide information that shapes the use of other tools that do intervene. As Fraser (2022) suggestively writes, but does not develop, "you can't eat data." For that reason, many have questioned whether precision agriculture's repair addresses the logic of these older systems, including reliance on biological alteration and chemical inputs and an abiding push for productivity (Bronson and Knezevic, 2016; Duncan et al., 2021; Fraser, 2022; Klerkx et al., 2019; Lajoie-O'Malley et al., 2020; Wolf and Buttel, 1996; Wolf and Wood, 1997; Wolfert et al., 2017). As put by Wolf and Wood, far from a public commitment and a technical mechanism to mitigate farm chemical pollution, precision farming can actually legitimate chemically-based agriculture.

Wolf and Wood further argue that precision farming is based on and advances the commodification of agricultural information—*appropriation* of field and farm-level decision processes to sell back to farmers, a proposition which many scholars have followed upon in considering the political economy of big data (Bell et al., 2015; Bronson and Knezevic, 2016; Carolan, 2018; Fairbairn and Kish, forthcoming 2022; Fraser, 2019, 2022; Giles and Stead, 2022; Wolf and Wood, 1997). At best, then, digital technologies give information to support less detrimental interventions to damaged ecosystems; at worst they allow the continuation of technologies causing harm in the first place.

For these reasons, Duncan et al. (2021), building on Lioutas and Charasari (2020), argue that it is largely the popular press that is positioning these digital tools as radical and disruptive, or even "game-changing." Duncan et al. further argue that the hype surrounding precision agriculture largely serves as a "way to shore up continued investment" from and for the tech sector, including both big players like Microsoft, and "a host of startups with *minimal previous connections to agri-food*" (p. 1194, emphasis added) and, we would add, minimal connection to their clientele. The implication is that precision agriculture has ushered in the tech sector's entry into farming and given rise to entrepreneurs entering the sector with limited knowledge, but a sense that their expertise in computational, artificial intelligence, and other tools has something to bring to agriculture (Miles and Smith, 2016).

Of further significance is that precision agriculture as a solution was not originally driven by farmer need or demand, but from the search for new uses for technologies that had been developed in non-agricultural manufacturing and the military (Wolf and Buttel, 1996). This "supply-side" understanding of agricultural research and development was originally argued by Busch et al. (1991), who emphasized that scientists, scientific institutions and technology developers have an interest in promoting particular technologies as solutions to problems. Precision agriculture, in that way, also exemplified the kind of technology transfer in which solutions seem to precede problems. Several aspects of precision agriculture, in short, provide a window onto the potential limits of the tech sector's introduction of digital technologies into the larger domain of food and agriculture, as those promoting digital tools are looking for new markets (Prause et al., 2021; Reisman, 2021). It is these aspects we wish to hold in mind as we analyze solutions emanating from the Silicon Valley-influenced tech sector.

Analyzing problems and solutions in the agri-food tech sector

Research reported herein is one slice of a larger, collaborative project investigating Silicon Valley's forays into food and agriculture. For this piece we were primarily interested in understanding the array of agri-food technologies Silicon Valley start-ups brings to bear. In general, analyzing such private sector activity can be challenging for researchers, and it is rare to find public information on companies that are not yet publicly traded. Fortunately, the tech sector is different, due to its predilections for self-promotion and hype-generation. Funders and consultants publish market maps, databases, and hold events, all to attract interest and investment in the sector. Utilizing this publicly available material provided us the opportunity to view the sector as it represents itself, rather than bring pre-conceived ideas of what the sector is or ought to be, and we have abided by this principle throughout our research. Although our research team has built a database of companies collected from a wide range of these publicly available sources, the database is noisy and repetitive, including, for example, consultants, venture capital funders, and incumbent corporations who have expressed interest in the sector. For the purposes of this article we opted to focus on a source of that data requiring no cleaning: a record of all the pitch events sponsored by FoodBytes!.

An offshoot of Rabobank, a Dutch financial institution which claims over 100 years of investments in the food and agriculture industries, FoodBytes! emerged out of and has been a premier player in defining and advancing tech-driven start-ups in food and agriculture. Though based in San Francisco, our point of entry, FoodBytes! has been hosting events much further afield, including New York City, Boulder, Austin, Montreal, Sydney and London, effectively gathering and showcasing agri-food tech from around the world. These events connect food industry leaders and investors with startup companies that, according to its website, are "innovating and disrupting the food chain with groundbreaking ideas in food, agribusiness and technology." Put in less hyperbolic terms, FoodBytes!-sponsored pitch events match eager start-ups with venture capitalists. Given that the standard format of pitch events insists that start-ups articulate problems and solutions, along with value propositions (Fairbairn et al., 2022), tracking the start-ups that have come through these programs provides an *in situ*, self-defined snapshot of the agri-food tech sector and its concerns. To be sure FoodBytes! cannot capture all innovation happening in the sphere of agriculture and food, much of which still continues to occur in universities and the in-house research and development (R&D) of incumbent corporations (which would be very difficult to obtain in any case). And its use necessarily slants the data toward early stage start-ups seeking seed funding and willing to work with incumbent corporations. Yet given our interest in what new entrants from the tech sector bring to agriculture and food, the Foodbytes! data is fitting.

As it happens, the array of products featured at Foodbytes! is quite typical of that offered in the sector writ large, as indicated in the many market maps we have reviewed and the data tracked by AgFunder, a venture capital firm that follows investment deals in the sector worldwide (AgFunder, 2022). It also roughly matches what we have witnessed in the many events we have attended sponsored by other parties, except those that specialize in a particular subset of the sector, say ag tech, or that are cross-sectoral, say biological innovation inclusive of pharmaceuticals. Further, the FoodBytes! website is unusually rich, listing all its alums and providing access to recordings of many of the pitch events. Analyzing this data thus allowed us to achieve more depth than an aggregate analysis of investments, products, or deals alone would yield. Specifically, we catalogued the featured products of 306 companies. This number reflects all that have participated in the FoodBytes! pitch events since its inception in 2015, up to their most recent publicly available event at the time of writing - a virtual event in 2020, except seven companies that left no discernable web presence. Drawing on their pitches and websites, we built out this catalog of products across several different dimensions including the product type, core sciences and processes employed, and a description of the intervention each product attempts to make in regard to a problem. This exercise was painstaking, requiring inference of ideas from less-than-lucid presentations and difficult decisions as to the dominant logic when ventures seemed to cross categories.

Although the detailed analysis of Foodbytes! participants comprises the bulk of our empirical case, qualitative data we have obtained in the course of our larger project suggests an explanation for our quantitative findings, even if partial. In our larger project, we have conducted over 90 interviews with startups, and investors, industry advocates and analysts. In these interviews we strive to cover a broad range of topics, only one of which is how start-ups define problems and develop solutions. In practice, many interviewees are not able to give us the time to answer all of our questions. Further, many tended to recite their pitches in the interviews. (As they say, “you’re always pitching.”) Contrary to expectations of qualitative research, then, these interviews did not necessarily give us a deeper understanding of entrepreneur motivations or meanings. So, for this article, we opted to use the limited interview material which provided deeper insight as to how entrepreneurs arrived at their problems, that which we coded for “problem and solution definition,” supplemented in one case with data we gathered from a blog interview. In addition, we drew on comments from the few interviews with investors and sector observers who spoke to the matching of problems and solutions in the sector.

T array of solutions

Existing representations of the agri-food tech sector found in market maps, Ag Funder reports, and even Foodbytes! programs use a variety of categories to describe the sector, often mixing products and technology. Most taxonomies provide higher level groupings, roughly differentiating novel foods, agricultural technologies, and food technologies. Those associated with ag tech essentially consist of appropriationist technologies, predominantly addressing problems at the farm level, while those in novel foods categories largely encompass substitutionist technologies, aimed at food manufacturers and eventually consumers. Other “food” technologies are generally oriented toward supply chain management, an area of intervention that was barely even contemplated by Goodman et al. (1987) whose concerns revolved on the biological exceptionalism of food production.

Finding that the categories provided by others miss something important analytically, we present a different portrayal of the array of technological solutions and products currently on offer, grouping the solutions on offer in relation to their apparent objectives. Table 1 depicts our analysis of products, grouped according to those that aim to transform, observe, streamline, or repackage. As we describe each of these groupings, we include exemplary articulations of problems in relation to the interventions, also drawn from our Foodbytes! dataset.

Table 1: Array of Foodbytes! Solutions by Objectives

	Core Intervention	# of Firms	% of Firms	Product Types	# of Firms	% of Firms
Transform (21.17%)	Microbiology	12	18.46%	Ingredients	11	16.92%
	Material Science	11	16.92%	Soil Applications, Fertilizers, &		
	Precision Fermentation	8	12.31%	Biological Additives	10	15.38%
	Molecular Engineering	8	12.31%	Packaging	7	10.77%
	Genetic Engineering	6	9.23%	Novel Feeds	6	9.23%
	Robotics	5	7.69%	Animal Biologicals	6	9.23%
	Hydroponics	4	6.15%	Automation	5	7.69%
	Cell Culture	3	4.62%	Indoor Agriculture	5	7.69%
	Process Engineering	2	3.08%	Manufacturing Process	5	7.69%
	Traditional Fermentation	2	3.08%	Animal Simulacra	4	6.15%
	Bioinformatics	1	1.54%	Equipment	2	3.08%
	Mechanical Engineering	1	1.54%	CPG	2	3.08%
	Electrical Engineering	1	1.54%	Ingredient	1	1.54%
	LED	1	1.54%	Aquaculture	1	1.54%
	Total	**65**	**100.00%**	**Total**	**65**	**100.00%**
Observe (13.36%)	AI/ Machine Learning	15	36.59%	Sensing & Analysis	15	36.59%
	Computer Vision	5	12.20%	Sensors & Monitoring	13	31.71%
	Data science	5	12.20%	Analytics Platform	11	26.83%
	Software Engineering	4	9.76%	Automation	1	2.44%
	Electrical Engineering	3	7.32%	Packaging	1	2.44%
	Bioinformatics	2	4.88%			
	Microbiology	2	4.88%			
	IoT	2	4.88%			
	Material Science	2	4.88%			
	Drones	1	2.44%			
	Total	**41**	**100.00%**	**Total**	**41**	**100.00%**
Streamline (20.52%)	AI/ Machine Learning	18	28.57%	Exchange Platform	15	23.81%
	Web Development	11	17.46%	eGrocery	14	22.22%
	Logistics	11	17.46%	Sensing/ Monitoring	12	19.05%
	Software Engineering	7	11.11%	Consumer app	8	12.70%
	Data science	4	6.35%	Digitization	7	11.11%
	IoT	3	4.76%	Automation	4	6.35%
	Blockchain Technology	2	3.17%	Consulting	2	3.17%
	Natural Language			Analytics Platform	1	1.59%
	Processing	2	3.17%			
	Genetic Engineering	1	1.59%			
	Bioinformatics	1	1.59%			
	Computer Vision	1	1.59%			
	Process Engineering	1	1.59%			
	Ingredient Processing	1	1.59%			
	Total	**63**	**100.00%**	**Total**	**63**	**100.00%**

Repackage + Other (44.63%)	Ingredient Processing	100	72.99%	CPG	107	78.10%
	Traditional Fermentation	10	7.30%	Animal Simulacra	5	3.65%
	Process Engineering	6	4.38%	Insect Farming	5	3.65%
	Systems Engineering	5	3.65%	Ingredients	4	2.92%
	Product Design	3	2.19%	Consumer Product	4	2.92%
	Data science	2	1.46%	Packaging	2	1.46%
	Web Development	2	1.46%	Equipment	2	1.46%
	Mechanical Engineering	2	1.46%	Supplements	2	1.46%
	Material Science	2	1.46%	Indoor Agriculture	2	1.46%
	Bioinformatics	1	0.73%	Consumer app	2	1.46%
	AI/ Machine Learning	1	0.73%	Soil Applications, Fertilizers, &		
	Molecular Engineering	1	0.73%	Biological Additives	1	0.73%
	3D Printing	1	0.73%	Irrigation	1	0.73%
	Distilling	1	0.73%			
	Total	**137**	**100.00%**	**Total**	**137**	**100.00%**

<u>Transform</u>

Constitutive of some of the most attention-grabbing and controversial products, e.g., cellular meats, precision-fermented proteins, genetically engineered novel feeds, a relatively modest 21.2 percent of products in the Foodbytes! dataset intervene directly in the biophysical world of food production by directly transforming crops, animals, food itself, or altering the material conditions of crop, animal, or food production. Products in this category mostly involve biotechnology (inclusive of genomics, tissue engineering, precision fermentation, microbiology, gene editing), molecular engineering, or material science. Products drawing on biotechnology or molecular engineering fabricate or preserve food, effectively improving on extant approaches to substitutionism, with a high proportion delivering protein in multifarious forms (Guthman and Biltekoff, 2022). Products drawing on material science generally produce replacements for plastics and other problematic material. The number of products using biotechnology in ag tech applications is surprisingly limited. Along the lines of appropriationism, these generally support livestock microbiomes as well as biological alternatives to synthetic fertilizers and chemical pest control. We suspect this is an area where corporate-university alliances remain the loci of innovation.

We include controlled environment agriculture and automation in this category, even though some of the technologies they employ are found in our next category. To explain: robots, a common form of automation, deploy visualization tools and artificial intelligence largely aimed at providing information, yet they supplant human labor and thus circumvent the limits and possibilities of human bodies. Similarly, contained agriculture brings together a complex array of software driven automation and mechanical infrastructure with lighting, temperature controls and biosecurity measures, yet these still directly transform the conditions of plant growth. We note here that only a couple of companies we categorize as controlled environment agriculture are actual operations; most in the dataset aim to provide supplies and infrastructure to commercial operations or sell directly to consumers for home use – the latter hardly world changing, but true to our criteria.

Consumer hydroponics notwithstanding, those developing the subset of products that directly approach biophysical problems of food and farming with (literally) transformative technologies tend to highlight the grander challenges of the food system as their core problems: the enormous environmental costs of now-standard fertilizer regimes, the risks of widespread antibiotic use in animal agriculture, the emissions, environmental degradation, and (to a surprisingly minimal extent) cruelty associated with confined animal feeding operations (CAFOs), and so forth. This is most obviously exemplified in alternative protein companies which hope that by utilizing novel biological processes to replicate or replace animal products, they will reduce their consumption and thus reduce the biophysical tolls of conventional animal agriculture (see, e.g., Guthman and Biltekoff, 2021; Jönsson et al., 2019; Sexton et al., 2019, among others). These companies are joined by those surprisingly few companies that are developing multi-microbial crop applications or other treatments in order to replace chemical pesticides and fertilizers in crop agriculture. Seeking to tackle problems of petrochemical-based single use plastics proliferating in the oceans and landfills, a handful of companies are developing packaging materials from municipal food waste that mimic or replace packaging material. Along similar lines, several companies are addressing food safety issues with biological and material science, using anything from cold plasma to charge air particles electrically and sterilize produce to supercritical carbon dioxide to render foods shelf-stable, along with a range of techniques for diagnostic tests. While such approaches are hardly exempt from critique – after all, these techno-fix interventions occlude other potential solutions to these challenges that fall outside the innovation economy such as enhanced regulation – we nevertheless see a close alignment between the biophysical base of the problems they identify and the solutions they offer.

<u>Observe</u>

The 13.4 percent of products that we characterize as having observational aims presumably inform treatments of biophysical problems but fall short of directly treating them. Dominated by the informational sciences most associated with Silicon Valley, virtually all of these products are digital, largely offering tools for sensing and data analysis in expectation that will provide useful information. As expected, these informational technologies are being applied beyond their original precision agriculture applications, with many products aimed at detecting and analyzing potential problems along the entire supply chain.

In articulating the problems they solve, start-ups may nod to big picture challenges of feeding the world, reducing waste, or enhancing sustainability, yet primarily address mid-range problems that appear amenable to digital technology's capacity to provide information and visibility. Many companies, for example, open with "feeding the world," while focusing on how their aerial imagery and in-field sensors will provide farmers with the information to allow them to improve yields, reduce unnecessary resource use, and allow more precise management. (They do not acknowledge concerns that improving productivity will aggravate technology treadmills and their negative effects on prices.) Several companies point to food waste's substantial contributions to global emissions, while detailing how their array of scales, computer vision, algorithms, and web dashboards will fill in the knowledge gaps around the constitution and quantity of excess food, presumably to inform better purchasing and recipe design.

Products aimed at making food production processes more visible are likewise geared toward informed decision-making. For example, innovators target the slow and bureaucratic approaches of pathogen testing as a major bottleneck in food processing with interventions as simple as bio-responsive stickers and dyes or as complex as point of production diagnostic tests using everything from DNA sequencing to light refraction. They also bring technologies of visibility to inform consumer practices by, for example, providing data on water consumption or nutritional components. Although the information these products provide may be valuable in changing farmer, food processor, or consumer behavior, they do not provide the direct tools to, say, decrease pathogen outbreaks or minimize waste. They thus serve as a reminder of the limits of auditing as correction (Dunn, 2007; Ponte, 2009), and those championing these solutions proceed as if measurement and visualization are tantamount to more sustainable management and behavior (Broad, 2020).

Streamline

Remarkably, a chunk of products (20.5 percent) emerging from the Silicon Valley ecosystem do not promise even indirect solutions to food and farming's grandest challenges. Some of these may be particular to food, for instance, products that help prevent spoilage of food or purportedly shore up farmer prices, yet they are effectively business solutions, providing anything from logistics, to personnel management, to marketing support.

To that point, many start-ups invoke inefficiency in articulating the problems they solve. In terms of products, this translates to software solutions aimed at streamlining any and everything. A bevy of "digital assistants" offer to streamline farmer's processes through AI and natural language processing-enabled record keeping. A couple of companies bring fintech to food tech by digitizing the relationship between farmers and grain elevators or coordinating short term financing. Following the path of disruptive start-ups like Uber and Air BnB, several companies create online marketplace platforms for specialized farm equipment and commercial kitchens that would otherwise be unutilized for significant periods of time. It may be, as Gianella (2015) has argued, that since efficiency is what tech can offer, efficiency becomes a proxy for the morality that Silicon Valley often lacks. That said, some of these digital products are not attached to discernable problem statements at all.

A look at the core sciences deployed in this category makes clear that the vast majority of applications draw on classic Silicon Valley expertise in web development, software engineering, data science, and AI. It is not entirely surprising that computer science and engineering are the dominant sciences applied in the space as a whole, given that many entrepreneurs left coding and the traditional tech sector to work with food. Many people we met at events and during interviews told us that very thing. Still, as entrepreneurs entering the sector transpose often off-the-shelf approaches from other realms onto agricultural and food supply chain management, the resulting solutions, such as platform-based coordination, are not always tailored to address the "grand challenges" that are supposedly animating Silicon Valley entry into agriculture and food.

Repackage

Perhaps what is most surprising is the large number of products (44.6 percent) that offer nothing obviously new, instead repackaging well-established products in food and agriculture. Of these, the vast majority in this category are consumer packaged goods (CPGs). CPGs refresh familiar forms, such as bars, bowls, and drinks, made with everything from quinoa to birch sap. Although producers of CPGs may use novel ingredients, say insects or byproducts of food or beverage processing, many do not employ novel production processes; instead they work with the well-established ingredient processing techniques of milling, mixing, baking, expeller-pressing, extrusion, drying, and so forth. Moreover, they often make well-established claims on their labels, e.g., organic, ethically traded, high protein, gluten free, or superfood. This category also includes several products used in organic farming systems, such as biochar and vermiculture composting systems, as well as a smattering of consumer products akin to kitchen machinery (e.g., a gadget that makes single servings of yogurt). It remains a curiosity why such products are in this space (and to be clear, the inclusion of such products is not unique to Foodbytes!). While this question deserves further research, we suspect that developers of these products seek out the funding and exposure offered by the tech sector that they have not been able to obtain elsewhere. This is not to cast aspersions on some of these repackaged products, surely some of which are useful and even beneficial; rather, their presence speaks to how the hype of agri-food tech has created opportunities for a great number of otherwise mundane products to come into the sector's folds, regardless of the degree to which they operationalize transformative technology.

Searching for problems

Positing the above, we asked many of our entrepreneur interviewees how they landed on their solutions. In response to our questions, most rehearsed their pitches and offered no more insight than what we have covered. Occasionally, however, they relayed stories of their own circuitous journeys into this domain. These stories seem to get to the heart of the matter: many entrepreneurs enter agri-food tech because it seems purposeful, exciting, and lucrative but bring with them solutions that may not hit the mark. These stories are the subject of this subsection, and we find their pivots and failures instructive.

The founding story for an exchange platform typifies this searching-for-a-problem dynamic in stark terms. Two generations removed from farming, one founder reflected that he had always had an affinity for agriculture, but his academic training in neuroscience funneled him into Silicon Valley along with "90% of neuroscience PhDs." After working in a few different health tech start-ups, he happened into ag tech through a design event where he met his co-founder. From there they "pretty quickly just sort of latched onto the shared sense of how fundamentally the main problem was to just make farming a desirable thing to do. And so we looked at commercial agriculture through that lens and saw just really similar solutions." And yet, despite their alignment with each other, they never quite landed on a solution aligned to the sector. They began as an equipment sharing platform, in their words an "Airbnb for tractors," but then came to the conclusion that farmers needed help negotiating with big agricultural dealers—"the people that sell things to farmers, like their chemicals and machines." So, they decided to shift away from the equipment rental business and become middle players, of sorts, to negotiate better input prices for farmers. Involving more phone calling than anything else, their technological aspirations fell by the wayside. A couple of years later they were out of business.

Another company whose founders similarly claimed passion about empowering farmers parlayed an expertise developed from decades in finance to deploy blockchain and then IoT technology in the food system. As the manager we interviewed put it, they "got tired of the fintech space, and so they were looking for another industry… And so they looked at music and insurance and education and identity, and then landed in the food supply chain." Beginning by digitizing tomatoes (whatever that means), they expanded into other food items with the objective to create "a digital twin of the supply chain." By capturing that data, they felt they could support companies in a quest to tell the story of the food they grow and bolster brand integrity. "So if they say that they're sourcing from sustainable farmers or from local farmers, we're going to capture data that supports that assertion." Thus, they latched on to the idea that revealing the conditions of production would be transformative without realizing their focus on increasing transparency and efficiency across supply chains would serve their corporate retail clients and end consumers more than the sustainable and local farmers they invoked.

Reflecting even more detachment from the biophysical challenges of food production was the case of a founder who had spent three years building a company that used machine learning to inspect road surfaces. The founder decided “it was a no brainer” to try such deep learning to look at plants and thereafter to use the expertise of botanists, horticulturalists, and viticulturalist “to understand the patterns on plants.” The company could then “embed that in the AI” and “just sweep across the plants.” The founder hoped to sell these “passive data collection platforms” to tractor manufacturers and was “absolutely certain that within five years,” it would “be routine in specialty crops or something.” When we asked what value that actually brought to growers, the founder replied that the technology could be used as a doctor or coach to growers. As a doctor, it could look for disease infestation, things that are damaging to a plant and then alert the grower to deal with it, like “You’ve got a COVID-like disease on vine 6, rows 7." As a coach it could suggest “some sort or remedy” – maybe “de-leaf” or “shoot thinning” or “some sort of water issue.” Here the founder never quite articulated a problem and demonstrated very little knowledge of the kind of biophysical problem that such a technology might resolve.

In the following case, the founder also pivoted from elsewhere, eventually discovering a problem that would articulate with the solution. This founder was trained as a mechanical engineer, had a brief stint in investment banking, and returned to engineering to develop computer visioning for robots. One robot the former company helped develop used computer vision to detect dog poop and automation to pick it up in people's backyards. (No, we’re not kidding.) Yet the founder realized that “trying to validate consumer demands for the next Roomba, or the next widget is a really tough sell,” and in consultation with investors, decided that addressing “a genuine pain point” was necessary. The company first looked into operations and logistics in developing markets, as well as point of sale services, but it was through meeting growers as a part of a California-based accelerator program that they learned of California’s historical dependence on manual labor and current farm labor shortages. “That’s how [they] came into agtech . . . It's probably the most impactful way you can get technology out the door, which is to solve a problem, which the world is currently really challenged by.” Eventually, they settled on a weed cutting technology for leafy greens. Although it remains widely controversial whether California’s historical farm labor issues are appropriately solved by robots, in this case, the company did eventually land on a problem for their solution, notably through an attunement to potential users.

Across these stories, we see a transfer of digital technologies and personnel from other sectors, a weakly construed, misinformed, or absent problem statement, and a solution that at best provides information, coordination, and (controversial but still transformative) labor saving, but does not directly alter how crops and animals grow or eaters obtain their nutrients or avoid pathogens. These stories can be contrasted with another published on IndieBio’s blog. An alumnus of both the biotech accelerator and Foodbytes!, this founder’s publically accessible interview details their journey to developing biological alternatives to fertilizers. In their words,

> I come from a farming family, so I know the importance of pest control to farmers. Without pest control, crop yield is reduced 50% to 80%. Therefore, I pursued an undergraduate degree in Agricultural Field Biology. I immediately recognized that biotechnology held great promise for agriculture. I pursued a

> Ph.D. in molecular and cellular biology, followed by postdoctoral training in chemistry, to bring discoveries in biotechnology to agriculture.

The company's first product was a bioengineered powdered additive to beneficial nematodes, which aimed to replace insecticides by enhancing the nematode's ability to target agricultural pests and to "allow farmers to protect their crops without toxic pesticides that poison our air, land, and water" (Liederbach, 2017). This story, in short, speaks to what is wanting in the others: deep familiarity with the biophysical challenges facing farmers and food purveyors and a solution tailored to a specific challenge of farming.

That solutions can be mismatched to the problems in the sector has not been lost on observers of the sector, including consultants, investors, and entrepreneurs themselves. While all who spoke to this issue noted the existence of companies genuinely interested in solving problems, we heard many cross-accusations of techno-solutionism. "Unfortunately, there's a lot of snow jobs are going on right now. It's like, 'Hey, we're going to go change the world,'" a consultant and investor commented. Another industry expert and investor put it even more bluntly, "So they're not actually fixing a problem. They can't." He went on to describe:

> I know people who have raised $5 million without ever talking to a farmer…Because they watch the news that farmers have a problem with drought, and water, and nitrates in the soil, and all this other ... 'Oh, well, I can fix that.' Four years later, they haven't fixed it. They've pivoted to do something else that makes sense to their investors to try to get some money coming in. So people don't listen to what farmers need.

One employee at a firm focused on diverting food waste succinctly described this common entrepreneurial approach as the "I found a solution. Is there a problem?" path.

Conclusion: Looking beyond digital solutionism

Silicon Valley and other innovation spaces have ventured into food and agriculture, claiming to meet some of the most daunting challenges associated with food production, distribution and consumption. These are challenges that scholars of agrarian political economy and critical food studies have long established as stemming from agriculture and food's essential biological basis. This same body of scholarship has shown how major innovations in food and agriculture, largely emanating from universities and corporate R&D, have been centered on attempts to overcome the vagaries of nature and biology, manifesting, for better or for worse, in tendencies toward appropriationism and substitutionism. We embarked on our analysis to assess whether Silicon Valley-style innovation was capable of improving on earlier rounds of appropriationism and substitutionism, by bringing novel agricultural technologies or reformulated foods that are allegedly better for crop, animal, soil and human health and the biophysical environment writ large. Putting aside for now whether the innovations are improvements, and even setting aside the conceits that these challenges can be met with technology, through so-called techno-fixes, our exercise shows that Silicon Valley brings a limited menu. Out of 306 products analyzed, only 21.2 percent wield biotechnology and material science to transform the materiality of food production processes in an effort to address biophysical challenges. Only another 13.4 percent aspire to deliver on the claims that the digital revolution is supposed to bring: better information and visualization to inform improved management and decision-making, setting aside that the decision-making such technologies enable does not necessarily lead to the reduction of harmful interventions. Indeed, of the digital solutions, the majority are designed to facilitate marketing, work out business inefficiencies, and otherwise provide whatever start-ups imagine digital products can provide. They may be tailored to the specificities of food and agriculture but that alone is not tantamount to tackling the grandest challenges. Together with CPG and other repackaged products, the presence of these products leaves a vast majority of the agri-food tech sector offering less-than-ground-breaking products.

Conceptually, we have married critiques from agrarian political economy and critical food studies to a critique of digital solutionism offered by Morozov, which emphasizes the problem of solutions ill-matched to problems or for which no problems exist. This marriage sheds light on both the mundanity of the majority of solutions that populate the sector and, crucially, the mismatch of digital solutions to the deeply biological problems of food and farming. Through our qualitative research, we have suggested that one of the reasons that these solutions are not well matched to the major problems of food and agriculture is that they have been transferred from elsewhere, by entrepreneurs whose entry into agri-food tech was not necessarily geared towards solving a particular problem. Rather, at least some appeared in the space as a means of gaining access to the capital and markets generated by this much-hyped sector, or simply because food appeared attractive or impactful. Thus, they came with solutions looking for problems, and those they found were not the sort that could be directly solved by the tools they brought. By no means does this approach characterize the entire field of innovation, but in keeping with Morozov, we do suggest that the character of Silicon-Valley start-up culture lends itself to backing into problems.

What does this all suggest about solutions that might make a difference? Not far below the surface of our arguments is a suggestion that serious solutions would deal directly with the biophysical challenges of food and farming. But this suggestion could too easily be read as a defense of technologies such as cellular meat and genetically engineered crops. That is not our point, especially since many such biotechnologies are attended by social and legal issues of grave concern, not least of which are proprietary rights around living things. For that matter, their environmental and nutritional effects also remain highly controversial. An embrace of technologies based in the life sciences can be read as quite hopeful or quite frightening and dangerous (Belasco, 2006; Lang and Heasman, 2015). And though it has not been a point of this article, one of the driving concerns of appropriationism and substitutonism is that these tendencies have shifted value away from the farm and into the pockets of incumbent input suppliers, crop and animal processors, and marketers. These political economic concerns must remain in the forefront, as does the core premise that many of the problems of the food system are political, social and regulatory that no techno-fix can solve. To be clear, a big part of the mismatch of problem and solution is because tech start-ups are tackling problems that simply cannot be solved by technology (e.g., food security with more yield, better nutrition with apps).

And yet, surely there are biophysical issues that need addressing with biophysical means. Although we did not find many, in our research we did come across start-up companies that were developing less hubristic ways to address them, working to repair past technological introductions. Such companies include the aforementioned company attempting to control pests without toxic substances, as well as a company using probiotics to strengthen and renew the cow's reproductive tract and the damage cause by antibiotic use. Others still are fermenting food waste to create bio fertilizer, and a few are making sweeteners out of plant proteins. This is not an unequivocal endorsement – all of these are technologies guarded by strong intellectual property rights often a demand of venture capital for them to obtain funding (Fairbairn et al., 2022). Nonetheless, they are quite arguably less damaging than the alternatives, and that is in no small part because they can support diversified farming and holistic nutrition.

But therein lies the rub. The tech sector entered into food and agriculture as a kind of third way to agri-food transformation, seemingly rejecting both a continuation of chemical-intensive, industrial food production, for being unsustainable, and a more decisive shift towards diversified, low input and localized agro-ecological systems, for being unrealistic. Put differently, they wanted to disrupt the sclerotic and damaging big ag and food companies, but essentially dismissed long developed alternatives in food and farming that had not scaled up – in no small part because those alternatives never received the support of the land grant universities or venture capital. (Indeed this dearth of support might explain why those behind some of these alternatives are repackaging them for the agri-food tech sector). Many entering the domain of agriculture and food also appeared to drink the Kool-Aid that industrial food is necessary to feed the world and did not always do their homework on the problems they thought they might address, instead bringing what they had to offer. Yet, in the final analysis it is really unclear that a sector comprised of many entrants attenuated from users, highly proprietary, geared toward venture capital profits, and often lacking expertise in food and farming has more to offer than those they dismissed. The fact that so many products either allow the continuation of the worse aspects of appropriationism and substitutionism or simply work around the edges suggests otherwise. It may be, in other words, that the problems of agriculture and food are better solved by those social movements and practitioners who have been in it for the long haul and whose attention to biophysical realities is something to learn from. At the very least their ideas might be heeded, not to mention their technological approaches funded.

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