population, the practice's bona fides were without blemish. But the biological data existed as artifacts of the site's infrastructure. When atmospheric testing ended in 1963 after the Partial Test Ban Treaty, the AEC and Holmes & Narver withdrew from the atolls. The concrete crumbled and the aluminum corroded. The technoscientific detritus that came to characterize so many terminated Cold War projects littered Bikini, Enewetak, and Rongelap. The infrastructure abandoned, Donaldson and the Seattle biologists no longer worked to maintain the biological truths that once kept the atolls safe, or at least kept the public back in the metropole believing they were safe. Their yearly trips stopped and they studied landscapes back at home.46

But the radiation failed to follow the program. It lingered and the Rongelapese got sicker and sicker.47 The body of each man, woman, and child exposed to fallout from Castle Bravo and the bodies of their children continued to create data about the bomb. But with Holmes & Narver gone, with the infrastructure dead rather than living, the biologists and doctors of the AEC found only marginal academic reasons to care. Like so many other boom and bust landscapes on the fringes of empire, the infrastructure at the Proving Grounds left a long-term legacy of sickness and tragedy for the local population and toxicity for the land and the sea.

8 * A Matter of Taste: Making Artificial Silkworm Food in Twentieth-Century Japan

LISA ONAGA

I first encountered silkworms in 2006. In a ten-gallon terrarium tank displayed in the Yokohama Silk Museum, they were eating a block of what looked like a dull green-colored paté. I felt excited to finally see silkworms after initiating my research on the history of silkworm genetics in Japan. At the same time, it puzzled me that I did not get to see them eat what every historical sericultural text that I had read promised they would with finicky dedication: mulberry leaves. In sericultural treatises of Japan such as Yōsan Hiroku of 1803, curious illustrations depict men and women harvesting leaves from mulberry trees by precariously climbing up into the arbor, cutting branches, and returning with bales of fresh fodder to the house where the mulberry leaves are then chopped and sprinkled over newly hatched larvae (fig. 8.1).1

The process of making silkworm fodder noted by the revered early nineteenth-century treatise required attention so as to match the hatching of young silkworms with the budding of new foliage that had to later be fed to the larvae, but before the formation of flowers. The expansion of mulberry acreage took the form of collecting and planting mulberry seeds, or a layering process known as toriki that trained low-lying long tender mulberry branches radiating from the trunk of an existing plant beneath the earth to serve as runners that could send down roots and establish a new plant clone.2 During the second half of the century, the distribution of land dedicated to mulberry fields reflected the growing importance of the plant for silk production. Mulberry fields occupied about 14 percent of all agriculturally available land in 1904 (231,400 chō), and grew to around 24 percent by 1933 (640,178 chō).3

This green substance the silkworms were chewing in 2006 is called jinkō shirō (人工饲料) in Japanese, which translates as “artificial feed” in English. This reconstructed mulberry is man-made and nowadays a “black-boxed” technology dispensed to classrooms, laboratories, and hobbyists where mulberry is hard to come by. It comes in different forms, from refrigerated, bologna-style packages sold on Yahoo! Japan for roughly US$20, to
powders. The packaged feed is sliced like cheese, thinly or into blocks, and fed to silkworms (fig. 8.2). The dehydrated powder mixes, which require no refrigeration, just require some water stirred into a “silkworm chow” (the name by which it is often marketed in the US).

The popular use of silkworms in primary schools usually focuses on the insect itself in order to teach young people early lessons about biological life. The use of artificial silkworm feed, often the only feed option available in the absence of mulberry, invites further questions about the human cultivation of biological life. This essay suggests that reflecting upon the food that silkworms eat and how that food has changed to allow new uses for silkworms—including in classrooms around the world where mulberry has been introduced—can lead to productive discussions about the relationship between humans and land use, plants and microbes, and animals that far exceed the insect itself. In some parts of Australia like Queensland, for example, Morus alba spreads easily and has earned an unwanted invasive status, although in Melbourne, the plants are integral for cultivating Bombyx mori sold to classrooms by “Australia’s most trusted Silkworm supplier.” Once introduced to create shade, planting new mulberry (and olive) trees has been banned since 1984 in Pima County, Arizona, as a means to curb pollen counts. Aside from highlighting changes in human land use, delving into the history of making artificial silkworm food may also prove a useful means for understanding the history of industrialized food manufacture more thoroughly. Plant-based silkworm feed may not involve the same combination of animal, grain, and vegetable ingredients used to make feed for goldfish, chickens, dogs, or cats; but highlighting how a concoction of sciences surrounding nutrition enabled the making of processed animal feed shows how key elements of industrial, rational engineering could enter the foreground of biology.

Artificial silkworm food directs attention to new aspects of the scientific history of silkworms in Japan situated in the world, as well as the history of biology more generally. Whereas previous research on the history of silkworm science has centered mainly upon the history of silkworm breeding and experiments leading up to what Japanese scientists have called keishitsu idengaku, or “morphological genetics,” the stuff of artificial silkworm food adds a twist to assumptions about the parameters of biological inquiry in Japan, and how inquiries about regimes of care in sericulture have persisted over time. Moreover, this history provides a counterbalance to the domination of breeding and heredity in the history of biology by they studies of domestication reaching back into archaeological records, or those of genetic research on plants or animals. The issue of “feeding”
located at the agricultural crosshairs of the intellectual field highlights nutrition and its relationship to political developments, a hitherto overlooked factor in the history of biological experimentation. Switches away from habituated food choices for livestock often indicate some deeper reason underlying justifications, be they food shortages or desires for food sovereignty. The switch to artificial food in the case of silkworms was not a leap but a process that manoeuvred through soya as a substitute for mulberry that raised questions as to why soya, and how food rationing or searches for human food alternatives, followed the military development of “Total National Mobilization” in Japan. The scientific relevance of the adage “you are what you eat” thus dovetails with historical questions about the materiality of the infrastructures of silkworm care and the seasonality of sericulture. Considering the observable shift in the feeding habits of silkworms from exclusively mulberry leaves to “artificial silkworm food” or “semi-synthetic food,” this brief history of making artificial silkworm food takes a step toward a deeper understanding of the twentieth-century molecular relationship between humans and insects, especially after World War II.

By asking what artificial silkworm feed is, means, and signifies, one can understand how the changing materiality of silkworm diet—its molecularization—resulted from a series of curiosity-driven and economically driven choices that occurred more disjointedly than seamlessly. Historical works on animal feed have gained sharper attention in the twenty-first century in the wake of outbreaks of bovine spongiform encephalitis, globalization, and concerns about genetically modified grains and derivations between food for animals or for humans. These contemporary concerns built upon earlier developments of the twentieth century to scientifically understand and optimize nutrition for livestock. By adding minerals, vitamins, or other chemical substances such as antibiotics or hormones, for instance, chickens could be cured of rickets, and cattle and sheep could mature faster and increase productivity. In addition, many of the concerns about the efficacy of raising animals for human food have been assessed and reassessed in view of the energy costs required to produce such food and intentions to determine how these externalities undermine environmental sustainability goals. These environmental concerns have been magnified even further by numerous environmental histories that show how the foods consumed by animals of agricultural value are at times tainted, with devastating effects, including extinction, due to a combination of toxic materials and metaphorically toxic politics that grant capitalist interests undue power.

The molecularly described and reconstituted silkworm food qua chow opens up an inquiry into the history of silkworm nutrition and biochemistry that genetics of the early twentieth century could only incompletely explain. At least two other questions are necessary to pose in order to deepen an understanding of the history of silkworm science in relation to molecularized understandings of the insect’s nutritional needs. First, what sociocultural, economic, and political conditions in Japan remade the conditions leading to scientific interests in making artificial food or granting silkworms with a new nature? Second, how should those intents to re-engineer the mulberry-silkworm interface be understood, if not only as purified efforts to define silkworm nutrition or to understand silkworm feeding behaviors? These questions facilitate an outline that maps upon two distinct eras in Japan, first in the aforementioned rise of total war mobilization in the 1910s through the onset of the Pacific War (scholars have referred to this period alternatingly as eras of fascism, militarism, and developmentally exceptional feudalism in modern clothing, owing to Emperor-worship wrapped in a mantle of nationalist ideologies), and the postwar occupation period shortly followed by the over-valORIZED “economic miracle” era. An overview of mulberry use and the situation of mulberry acreage in Japan spans these two eras in the mid-twentieth century; moreover, the focus on mulberry itself sets the stage for analyzing the consequences spurred by the then-emergent prospect of colonially available soya. A reconstruction of the different approaches to researching silkworm feeding behaviors by Japanese chemists and geneticists operates in a foreground lush with mulberry, against a much more distant background of soya. Experiments released questions about why silkworms seemed to eat mulberry exclusively, and they also motivated the development of silkworm nutritional physiology. These and other scientific engagements leading to “artificial” feeding practices were a byproduct of dealing with the space in between the imperial expansionist agenda and nation-building projects. A discussion addresses the postwar use of artificial silkworm food for re-engineering the macro-level strategy of sericulture for the nation. The essay ends with some contemplation as to what silkworms have become useful “for” and to whom.

Mulberry at a Glance

Over twenty species of mulberry are found in Japan, and among these, the most widely cultivated is *magnusa* (マツガ), or *Morus alba*. Commonly known as white mulberry for the color of its young fruiting body (that later turns red-purple), leaves of dried mulberry leaves are used to treat high blood sugar and weight loss, among other things. Since the ancient period, however, the main purpose of moriculture has remained to provide fodder for silkworm larvae.

The nutritional content of mulberry leaves depends on several things:
the variety, season of harvest, locations on a branch, geography of cultivation, soil and fertilizer, method of cultivation, and sunlight. These things explain the range of crude protein content of mulberry leaves, for nature does not produce a standard mulberry leaf. Leaves grown under shaded conditions produce less protein compared to those of sun-exposed conditions. Common sense understandings of when and how to collect and dispense mulberry leaves belied the complications of developing artificial food suitable for silkworms of different developmental stages.

The variability of mulberry leaf compositions posed a sufficient challenge to scientists historically in pursuit of understanding the nutritional requirements of silkworms. On the one hand, this was a familiar issue, exemplified by efforts in the late nineteenth century to standardize silkworm rearing practices and to determine the weight of leaves necessary to feed a given number of silkworms and generate a certain volume of cocoons. On the other hand, we can understand the nutritional requirements of silkworms as a more recent problem that is less about making a table of conversions and more about developing substitutions for mulberry leaves. This twentieth-century look at sericultural science falls upon mulberry and efforts to disturb the exclusive nutritional partnership it has with *Bombyx mori*. Silkworm nutrition formed a major counterpart to the genetics of the silkworm that began to define a growing field of twentieth-century sericultural science research.

Before delving into the key experiments connected to the problems of silkworm nutrition and how molecular sense of mulberry was made, let us review some of the problems that faced the Japanese raw silk industry in the twentieth century. About 2.2 million farming families in Japan engaged with sericulture at the height of Japan’s silk production and export in 1930 before the effects of the stock market crash were felt fully. A look at agricultural land use dedicated to mulberry farming according to Ministry of Agriculture reports shows that the 707,550 hectares of land then allocated to mulberry cultivation yielded about 400,000 tons of cocoons. For key silk-producing areas like Gunma Prefecture, mulberry occupied as much as 47 percent of the farmed area. After World War II, the price of raw silk collapsed even further as the USA stopped importing raw silk from Japan, coupled with the development and popularization of synthetic fibers. Yet, the GHQ (General Headquarters, Supreme Commander for the Allied Powers In Japan) and the Japanese government agreed upon a Five Year Emergency Rehabilitation Plan for the raw silk industry. This plan, which went into effect on August 13, 1946, consisted of a forceful government policy to maintain the acreage of mulberry (170,000 chōbu, roughly 170,000 hectares) in Japan. Already, farmers were digging up their mulberry trees in favor of growing other crops that were less laborious and involved less risk. Even if they did not destroy their trees, the possible neglect of mulberry added to concerns of Japanese abandonment of sericulture altogether. The five-year plan laid out an ambition to recover the silk industry enough to export at least 10,000 bales of raw silk per month, if not more. Farmers were guided to follow the policy under the expectations that the prices of cocoons would increase. The dwindling mulberry acreage following the war may seem like a logical explanation for the initial development of artificial silkworm food. Although mulberry does regularly figure in postwar Japan, the actual story of making artificial silkworm food reflects a pitcher development that bridges economic concerns of pre- and postwar sericulture with scientific inquiries into the biology of silkworms.

The prewar investigations circling around what silkworms eat, why, and how, would call into question not just what was appropriate nutrition for silkworms, but what was mulberry in a molecular sense. These intertwined with matters of Japanese colonialism, desires to avoid microbial diseases transmitted to larvae by consuming infected leaves, hopes to industrialize production, and intellectual questions like why silkworms eat mulberry. At the most pressing level, the problem of completing a fall season of sericulture successfully depended on overcoming problems caused by feeding silkworms yellowing leaves. Seasonality features prominently in sericultural materiality, and this challenge of taking advantage of autumn leaves with their diminishing nutritional content propelled feeding studies to understand how to supplement the silkworms.

What’s Soy Got to Do with It?

“Silkworm chow” is a compound of powdered mulberry, starch binders, and nutritional substances such as soybean extract or purified amino acids, among other things. In some cases, especially in Japan, it is possible to purchase the food in a raw form, but otherwise, a human must reconstitute the powder with water. Although information about some European experiment reports of adding hormones and amino acids to silkworm diets reached Japan through translation of abstracts, these results reported negligible effects in the cocoons. Despite various feeding experiments that also continued in Japan involving carbohydrates, vitamins, inorganic salts, lipids, and other substances like thyroid powder from animals, these for the most part did not lead to increased rates of development nor did they yield larger cocoons. Instead, the process of arriving at an ideal formula interestingly seems to have begun with the proteins found in soybeans.

The precipitous fall of silk cocoon prices after 1929 served as an indicator of economic health in Japan, which led to manifold responses.
Manchuria, the northeastern-most tip of present-day China that Imperial Japan invaded in 1931 and subsequently opened up for settlement, offered Japan a range of alternative autarkic hopes and promises. By 1932, the Rural (Farm, Mountain, and Fishing Village) Economic Revitalization Campaign particularly encouraged farmers to seek out their own solutions for economic recovery from economic crisis. By encouraging education, farm management, and village culture and social life, the vast reforms made possible by the Ministry of Agriculture and Forestry’s 80 percent budget increase ultimately served to prop up the small villages in Japan over the span of three years. This movement differed from the late 1930s German effort to create a peasantry by establishing hereditary homesteads and enlisting young men in the Arbeitdienst (Reich Labor Service). Yet they share some similar motivations, such as the recovery of farm debt and curtailing food shortages. In Germany, the desire to eliminate dependence on imports such as animal fodder (e.g., fish and meat meal, bran, other grains) had motivated the Nazi policies that sought to control the production and distribution of agricultural products, and to carry out settlement and reclamation activities. Meanwhile, public works projects in Japan developed at the same time as the Economic Revitalization Campaign in order to increase wage-earning jobs. The tasks that the Home Ministry could fund included the redevelopment of mulberry fields, which notably included the labor of some women farmers as well.

As historian Kerry Smith has observed, the Economic Revitalization Campaign occurred on a highly localized scale, in which village reforms were directed inward, making several thousands of villages more uniquely operable, although the structure of procedures, like submitting proposals to the Economic Revitalization Committee in order to strategize plans for earning income, did lead to trends that could be observed later on a national scale. In Smith’s case study of the village Sekishiba in Fukushima Prefecture, sericulture had slowly become edged out of strategic focus in view of the need to free up acreage for food production. More generally, not only in Fukushima where mulberry cultivation was crucial fodder grown for silkworms, farmers and planners were expected to produce as much mulberry on their remaining fields as they had before the campaign took effect.

As the radical and utopian arm of economic revitalization, Manchuria symbolized an economic panacea. Manchuria began as an economic security strategy that had to handle the rural population and poverty in the home islands. Most of the Japanese emigrants hailed from northeast Japan’s silk-producing region, the Tōhoku region. Sericulture was Tōhoku Japan’s main revenue source until the Manchurian Incident in 1931, which prompted consumer boycotts in the US and a crash in Japanese silk prices. It was not motives to purify Japan of the ills of overpopulation, but as historian Louise Young has explained, these price drops, compounded by rice crop failures in 1933 and 1934, particularly catalyzed the disproportionate migration of 66,522 individuals from Tōhoku; and Manchukuo, as the client-state was called after 1934, reached a population of 1 million in 1940. In the context of a stagnant silk trade, the steadily growing soybean industry must have appealed to Japanese farmers, many of whom had worked originally in the heart of Japan’s silk country, Nagano Prefecture. The land in Manchuria was viewed by planners as a space that could accommodate a military reserve and food. Its inhabitants also absorbed Japanese exports, including yarn and cloth and textile piece goods. The idea of Manchukuo had morphed into that of a sovereign destination yet its affordability of fused technocratic, bureaucratic, and military control was also understood as a means to overcome the shortcomings of Japan’s original natural resources. Such juxtaposition marked Japanese fascism. It is in this imperial and extractive context that technological endeavors and ideology coupled with national political and economic decisions and ideologies about multiethnic authenticity.

Japanese reliance on Manchuria’s resources existed long before Manchukuo did, as demonstrated by the import of cakes of soybean lees, the byproducts of the extraction of plant oil, in the previous century. The nitrogen-rich lees were used mainly as a source of fertilizer until fast-acting synthetic fertilizers came into use in the 1930s. In addition, the lees have been used, including to this day, as animal feed and media for microorganisms. Soy’s demand did not diminish, as it easily fulfilled demands as livestock fodder. The settlers’ attraction to Manchukuo thus included tantalizing promises of livelihood that included soybean cultivation. From Japan’s perspective, Manchuria was an important granary. Of the world’s soybean-producing regions, the projected output of Manchuria’s soy was an incredible 208 million bushels compared to Japan’s roughly 15 million. The settlement and control of Manchuria not only meant a supply of food, but also promised a ready source of fertilizer resulting from the byproducts of soybean oil extraction. While the oil was used for cooking, lubrication, painting, and illumination, the 64-pound cakes of soybean lees presented an alternative to fish fertilizer used for enhancing the growth of mulberry plants (and rice) on the home islands of Japan. Although the export of soybeans was widely appreciated, the plant was not a total panacea. In the “soy frontier,” historian Sakaki Christmas has examined, the cultivation of soy in Manchuria also led to depletions of selenium that led to Keshan disease, but this did little to change land use. Instead of remediating the environment, the ministration of mineral supplements to people salvaged only human health.

Still, soybeans commanded an appealing interpretive flexibility. Encour-
agement of soybean cultivation among the emigrants may be especially understood as part of Japan's imperial quest for economic autarky. The scientific soybean experiments that took place during the 1930s and the aura of the critique of capitalism must be understood in the light of the strategies of Manchukuo's planners to bolster the soybean industry in the 1930s. Experiments of the plant itself underscored a multitude of uses alongside the energetic promises embodied in soybeans. These experiments focused on questions about how to microbially enhance its delivery as a fertilizer, the optimal growth requirements of the plant (including disease control), potential industrial applications, how water content relates to soy sauce production, and the protein content and nutritional value of the beans for humans and animals. Uses for soybeans were also explored in Manchuria. In 1933, the journal Shōyū to Miso [Soy Sauce and Miso] published a short piece that reported on the successful feeding of a mixture of soybean and mulberry leaves to silkworms. The experimenter, identified separately in a sericultural journal as a certain Mr. Naruse of the port city of Dairen, had immersed and boiled mulberry leaves into a soup of soybean lees and fed them to larvae up to the third instar. After that, the lees alone were said to be used as feed. Although the exact recipe was not made clear, the article heralded the reality of lowering the overall cost of raw silk production by half, and boasted that this innovation would undoubtedly impress the founding fathers of Japan's raw silk export trade. Three months later, the journal reported that soybean lees were used as silkworm feed for the first time in Japan, in a village of Kagawa Prefecture, but the larvae reached their cocoon-spinning stages at a slower rate. Despite the various competing ideologies about self-sufficiency, the highly particular activities of individuals residing in Manchuria connected back to a paradoxical substrate of Japanese activities dependent upon Western capitalist markets. Manchuria's transformed landscape, both environmentally and figuratively, provided a ground for imagining and prototyping new applications of soybean lees for use on the home islands.

The soy experiments that unfolded represented inquiries into how to maximize plant resources. These interests entailed scientific questions engendered by the particular constellation of networks and concerns that constituted the geographic space of the client-state of Manchuria. The groundcover of soy fields converted from boreal forest point to an embodiment of autarkic priorities and institutional, formal, and informal networks in the making of particular crops in fascist regimes. On an institutional level, the Japanese colonies had their own agricultural experiment stations that extended from a network of agricultural and sericultural experiment stations on the home islands. In colonial settings in Taiwan and Korea, agricultural experiment station scientists surveyed and prospected indig-

Toward Molecular Understandings: Silkworm Feeding Behavior

The enthusiasm for feeding experiments was more practicable on the home islands. In the late 1930s, studies that extracted carbohydrates and the protein glycamin from soybeans developed, taking the research onto a molecular scale. One aspect of research focused upon the biomolecular content of the mulberry plant, which paved the way to test supplements for silkworm diets. Feeding tests by Ito Toshio, a scientist at the Sericultural Experiment Station, sought to develop feed to compensate for the loss of proteins and sugars from autumnal mulberry leaves. In these feeding tests, the scientist developed several versions of enhanced feeds including things like kinako (parched soybean powder), potatoes, and regular soy protein powder that could be sprinkled over top of mulberry to deliver glycamin as well as other nutrients into silkworms' bodies.

Aside from the analysis of mulberry leaves, interests in the physiological chemistry of silkworms had also emerged as another facet of the nutritional science of silkworms. In the 1930s, the behavior of the silkworm had attracted the attention of chemist Hamamura Yasuji (1901–1985). He had neither training nor background in entomology, but when he took a post at the Kyoto Institute of Textile Fibers in 1935, he explored the question of silkworm monophagy. Something about the fresh, leafy aroma of mulberry leaves must have attracted silkworms to the plant, he thought. So, he placed fresh young mulberry leaves in chilled ethanol to create an
extract, which he then separated using paper chromatography. When he placed this filter paper near silkworms, they gathered toward it as they would gather toward mulberry as he expected, but none of them tried to bite the paper. Hamamura continued several other experiments such as soaking the leaves of sakura or poplar trees with the extract, but these did not yield behaviors of actual eating. It would not be until after the World War II that Hamamura would isolate the other chemicals critical for understanding the sequence of things necessary for a silkworm to ingest food.  

Hamamura's efforts to understand silkworm feeding behaviors from a molecular vantage can be appreciated in hindsight as joining up with earlier studies in dietarily enhanced soybean powder in a vein of research on polyphagy. Additional research framed around the question of why silkworms eat mulberry exclusively added to this. Around 1941, the silkworm geneticist Tanaka Yoshimaro (1884–1972) carried out rudimentary experiments of sprinkling dry mulberry leaf powder over top of lettuce leaves in order to entice them to eat.  

The method, which allowed silkworms to enter the cocoon-spinning stage, lent promise to the rearing of silkworms in midwinter.  

Testing silkworm feeding behaviors carried on after the war. In a 1945 experiment published in 1948 by Torii Ichio and Morii Kenzuke, removal of one of the two maxillae of the silkworm inhibited its ability to differentiate between mulberry and other leaves such as sakura and cabbage.  

Whereas Torii was quite confident that the biomechanics of the mandible determined feeding choice, subsequent research by Itō Toshio showed that the maxilloctomized larvae did not continuously eat these sakura and cabbage leaves as they did eat mulberry. A follow-up mandible experiment in 1959 with Yashiro Horie and insect nutrition scientist Gottfried Fraenkel of the University of Illinois (who also published a now-classic paper in Science in 1959 that opened up the field of insect-plant coevolution) concluded that taste organs other than those on the maxillae must exist.  

A new generation of scientists using genetic approaches simultaneously joined the band of chemistry and microsurgical experiments investigating silkworm polyphagy. In the 1950s, silkworm geneticists like Tazima Yataro (1913–2009), a protégé of Tanaka, developed a mutant strain of silkworm without feeding inhibitions, allowing it to eat apples and chard, among other things.  

Tazima believed that food preference in silkworms had to do with the sensory organs in the maxillae. Since 1952, he had begun experiments with X-rays to induce mutations in silkworms with his assistant Kobayashi Kazuo. Using chard to test the responsiveness of resulting silkworms to detect any such mutations was a trial-and-error process. First, the bite marks of first and second instar silkworms were too small to detect. Second, it turned out that chard was toxic for silkworms, so as soon as the scientists noticed bite marks, they had to remove the silkworms and place them onto mulberry. Even though they were able to count 114 larvae out of 37,900, the silkworms fared so poorly that only one male matured to produce offspring. In a second round of experiments, they produced 314 mutants that could eat soft leaves such as those of chard, sakura, persimmons, satsuma oranges, and soybeans. Tazima and Kobayashi published the results of breeding these resulting silkworms for ten more generations in 1954. From this genealogy of silkworms, they eventually identified the chromosome location of the gene for this nonselective eating behavior.  

Understanding that similar mutations could have occurred naturally, Yokoyama Tadao suggested the need for the Sericultural Experiment Station to survey existing strains for similar mutations. Yokoyama indeed found individual silkworms among Japanese and Chinese strains that responded positively to cabbage and these were interbred, forming a line known as Sj (IRJ). The strain was also known to eat other things: leaves of apricot, cherry, and persimmon. The study of this Sj line was shown to have genetic congruence with the mutant found by Tazima. That said, breeders did not use these silkworms, due to their inferior cocoon quality. Additional researchers would go on to study the physiology and biochemistry of silkworm feeding itself, constantly blurring the lines of where practical application and basic research began and ended.  

In the 1950s, Hamamura also resumed his experiments, which provided a clearer picture as to what chemical substances governed the exact feeding behaviors of silkworms. He placed silkworms onto the remains of a mulberry leaf that had undergone extraction. The silkworms ate the venous remnants of the leaves, which gave him a clue about the molecules that were necessary to induce silkworms to perform the action of biting. Hamamura carried out other extraction experiments with acetone and methanol to pinpoint the substances that were necessary to make the silkworms bite. A third substance was also identified as necessary for the subsequent action of swallowing by the larvae.  

Since then, Hamamura's biochemistry laboratory gained fame in the silkworm science community for developing an agar jelly based diet containing the three categories of factors necessary for sustained eating by the silkworm: Attractants, which included citrus (also found in mandarin orange [Citrus reticulata] and trifoliate orange [Citrus trifoliata] tree leaves), tepinyl acetate, linalyl acetate, linalool, and β-γ-hexenol; biting factors (beta-sitosterol and isotoicetinor morin); and swallowing factors (cellulose), as well as co-factors (sucrose, inositol, inorganic phosphate, and silica).  

The infusion of the agar medium with chemical agents was spurred by work in the laboratories of Robert Koch and his disciples in Japan, including bacteriologist Kitasato Shibasaburō (1852–1931). While agar
was used increasingly to encourage the growth of microbial life, it is also curious to consider the underexplored historical relationship between Japanese culinary consumption of kanten (agar jelly cubes) and experimental biology practices in Japan. As early as 1917, Drosophila scientist J. P. Baumberger had developed a banana agar medium that he argued made it possible to observe behaviors such as oviposition that would have been difficult to do with conventional medium of fermented banana. Following this, geneticist Komai Taku formulated a recipe for agar-based fruit flies medium by 1927. While Hamamura's citation choices do not suggest that the Drosophila system was a direct inspiration, his work shares a connection with the need to clearly observe insect feeding behaviors and the usefulness of agar-based media. The discussions in Hamamura's papers do not project an intention to develop a new diet for silkworms. That said, the subsequent synthetic silkworm diets developed by other teams built upon Hamamura's key work.

Artificial Silkworm Diets

The development of technologies for growing pure bacterial cultures in the nineteenth century presaged broader inquiries concerning the growth of living things in laboratory conditions. Endeavors to create artificial silkworm diets in the 1950s and 1960s, largely practically motivated by interests to enhance cocoon yields, dovetailed with broader scientific questions that were surfacing about the nutritional requirements of insects, not only in relation to the development of feeding media for research insects like Drosophila and Ephesia, or fish kept in captivity. Research into the phytosterols, lipids, proteins, and growth factors necessary for the silkworm diet continued into the later decades as scientists sorted out what would guarantee stable and ideal growth.

The relationship between silkworm diet and silk quality and yield highlights another dimension of the research that went into making jinkō shirō. By the late 1950s, the scientific thought prevailed that reducing the percentage of crude ingredients with purified compounds would lead to better larval growth and thus larger cocoons and greater egg production. The processes of “improving” the artificial silkworm diet thus also prompted the analysis of the insect's nutritional requirements. For example, the diet developed by Ito reduced the crude mulberry content to ten percent. Bound with potato starch, sucrose, defatted soybean casein, hemosan’s salt mixture, and cellulose powder, this diet tested the effects of the presence and absence of other extracts from soybean powder. Soybean oil had previously been shown to help prevent outbreaks of flacherie disease in larvae, but its nutritive value was yet unknown. This 1960 experiment by Ito helped pave the way to eventually show that the soybean oil's sterol and fatty acids together functioned integrally as a growth factor that facilitated the normal molting and growth of the larvae.

Scientists continued to try to develop diets consisting of simple nutrients without dry leaf powder. In 1962, a team at the Sericultural Experiment Station led by Fukuda Toshifumi tested three types of diets consisting of different ratios of potato starch, sucrose, amino acid mixture, vitamin mixture, mineral substance mixture, cellulose powder, f-sisterol, alcohol extract of mulberry leaves, and water. Their results, published in Nature, showed a clear possibility that silkworms could persist on artificial food. Interestingly, Fukuda highlighted that different “races” of silkworms (Japanese, Chinese, European) perform differently per diet. This was but a small comment, but it is mentioned here in order to remind that the vestiges of earlier decades of genetic thought intertwined with the newer biochemical analyses of silkworm nutrition. Above all, the qualification reminds that the concern that propelled this research was not about simple viability of the food that would permit the breeding of a next generation of insects, but that the nutritional content would also allow the larvae to spin cocoons of a certain decent quality. The overall rate of growth and development of larvae raised on artificial diets would become more reliable but could not replace the efficacy of mulberry leaves.

The pursuit of a semi-synthetic diet for silkworms continued. In 1966, Ito developed an amino acid diet that did away with powdered mulberry leaves and soybean casein and used amino acids as the sole source of nitrogen. On a practical level, semi-synthetic diets allowed minute adjustments to their compositions in order to meet the needs of one of three qualitative stages of larval growth (starter, grower, producer). Although larvae on semi-synthetic diets can spin cocoons, the feed is used primarily for the sole purpose of nutritional investigations into the insect.

Re-engineering Sericulture with Artificial Food

The history of scientific investigations into silkworm feeding behaviors and the development of a viable artificial medium for growing silkworm larvae have illustrated the continuity of research across wartime. Attention to Japan's postwar development with respect to the commercialization of silkworm feed sheds additional light on the continuity of this research. Plans for the wider-scale use of artificial silkworm food involved revisiting sericultural planning at the national, prefectural, and corporate levels of governance. The rationalization of sericulture in the postwar period would not only strike a familiar tune of macroscale strategizing. It also meant that the regulation of artificial silkworm food itself would be used
to re-engineer Japanese sericulture for its survival in the postwar period, especially after 1952 following the Allied Occupation of Japan.

For sericulture industry stakeholders, artificial silkworm feed served as a technological answer to the dilemma of how to revive the silk industry of postwar Japan, namely by intervening in workers’ wage distribution. The specialization of sericultural work that had supported the Japanese silk industry since the Tokugawa period had continued to encourage integration of diverse rural and cottage-industry economies into a capitalist system as silk production and trade intensified through the 1920s and 1930s, to sell high volumes at low cost. Many of the underlying reasons for female laborers’ unrest in the textile sector, such as low wages and long working hours, carried over to the 1950s. The silk (and cotton) spinning industry was compelled to elevate its labor standards, which included retreat from infringements on personal freedoms and increasing wages. Among those idealized interventions was the notion of economizing the amount of mulberry fed to silkworms. The concern was not so much how to offset agricultural labor and cost required to cultivate mulberry to generate silk, but how to increase the output of silk without a commensurate acreage of mulberry that would have been normally grown as supplemental income by farmers.

The idea of artificial silkworm food, seeded in the imagined potential of Manchukuo’s soy fields, gestures to a turn in which the driver of self-sufficiency gradually manifested in the economic aspirations of a reintegrated postwar Japan. Although most discussions of revigorated postwar managerial practices refer to assembly line manufacture linked to Japan’s expansion into new markets and the diversification of goods, a commitment to high growth and production optimization was shared across the sectors. One may especially understand the excitement surrounding the potential of artificial food in the light of the growing costs of female labor in textile factories and efforts to move forward from the era of management by coerced obedience with data-centric scientific labor management. In contrast to the time it takes to cultivate mulberry plants from seedlings to maturation and the labor costs not just to pluck the leaves (at the height of the fourth instars of the voracious caterpillars), but also to cut entire branches and haul them on trucks and distribute them to farms, the continued interest in using soybeans to make portable artificial food during the postwar era symbolized the growing appeal of emergent scientific management priorities to economize and gratify the compulsion to produce silkworms again on a scale as before. The regularity of anticipatory news headlines in the 1970s such as “わがマスアカロ時代 人工飼料の予想認む “高級毛織をめざす” ("Even silkworms in the age of mass production: Budget for artificial feed set—Sericulture factories’ without mulberry fields"), which appeared in the Asahi Shim bun on December 27, 1973, must be understood in the scope of the developmentalist discourse marked by the 1960 Income Doubling Plan. The plan focused on creating economic growth through enhanced productivity facilitated by improved management—high wages ensured by low costs. The vibrant clashes between workers and managers that surfaced throughout the 1960s are just as much a testament to that period of “modernization” of Japanese enterprises as were the training of scientists and technicians, and the development of new industries, encouraged by the government.

Although artificial silkworm food was no icon of Japan’s so-called economic miracle, it was certainly a product of its time. Its development followed the era of efficiency-driven adaptation of ideals weighed by the heavy industries involved in making power looms and other machinery for textile factories in the early 1910s and 1920s, which helped implement time-consciousness in factories that employed great numbers of young during the interwar period. Apart from the layoff of factory workers, the devalued mental and manual skills of farmers never fully recovered after the global recession and the onset of the Pacific War. The introduction of artificial silk (rayon/viscose) by this period has often also explained the demise of Japan’s silk trade. Interestingly, this period saw a plenitude of Taylorite ideals that were not actually implementable on the floors of the numerous yet small textile factories of Japan; scientific management rather centered upon the rationalization of government policies concerning industry. The new project of making artificial silkworm food embodied the reckoning with tensions as Japan shifted the investment of its resources from low-return agricultural sectors to higher-return non-agricultural sectors. It promised cost-saving enabled by reducing dependence on land for mulberry that would in turn minimize labor costs. Above all, artificial silkworm food was seen as a strategy to prevent the eclipse of the relevance of silk for Japan—or of silkworms, at least, by bringing the focus of concern to neither the factory floor nor to government policies alone, but to the interface between plants, insects, and capital once again.

The history of the research surrounding artificial silkworm food helps show the creative ways by which Japanese scientists, technologists, government, and sericulture endeavored to maintain the salience of silk. The restriction on the commercial release of artificial silkworm feed until 1977 represents the value of coordination between various government and private entities. Deliberate time buffers encouraged the co-development of new products and plans while reorganizing existing silkworm nurseries. At a glance, the release date may seem arbitrarily set by the government in a top-down fashion, but it indicates a close public-private sector relationship that took into account mutual practical understandings of the
state of research and its potential, alongside shared anticipations about how the silk industry fit into overall anti-agricultural trade liberalization concerns. As a response to the demands for an open market dominated by the US, these discussions bore a reminder of earlier utopian calls for self-sufficiency. Above all, they generated an aura of competition both within Japan and amongst new corporate entities in agriculture and reconfigured silk industries. For example, in 1975, Japan Fertilizer and the Saitama Prefectural Sericulture Farming Cooperative Association collaborated to manufacture 30,000 liters of “Mayugen,” a nutritious additive feed made from rice and chlorella (single-celled green algae) designed to be sprinkled over mulberry for silkworms. Its anticipated price of 1400 yen per liter claimed to help reduce the actual volume of mulberry leaves distributed to larvae by twenty percent and elevate the production of cocoons. The animal feed company Nihon Nōsan Kōgyō Corporation (NOSAN) entered the fray in 1976 when it announced its plan to develop and commercialize artificial feed for sericulture, with the aim of reducing costs even more by cultivating their own mulberry fields and finding alternatives to expensive agar. The Ministry of Agriculture and Forestry regulated silkworm feed quality by inviting companies to submit their artificial feeds to trial in advance of 1977. Five companies participated: NOSAN along with Takeda Pharmaceutical, Katakura and Gunze Corporation (two famous silk reeling companies), and a food company Ajinomoto, known for manufacturing a flavor enhancer for human food, monosodium glutamate.

While some observers opined that farmers could perhaps use their freed acreage for growing other food crops, the trial runs, model manufacturing plants, and infrastructural redesigns that aspired to fit artificial feed into actual sericultural practices concerned those on the ground in different ways. Silkworm reapers who participated in the trials reported that it took silkworms several extra days to spin cocoons. Moreover, among the smallholders left in the postwar period, worries abounded that the silk industry would change too much and prioritize the larger organizations that were committed to the ideals of mass production. For scientists, the project of artificial feed both diversified the scope of silkworm science and opened up new research inquiries; it also ensured the relevance of silk research, for instance, through biochemical analyses of the two silk proteins, fibroin and sericin, into their amino acid components. In this sense, I suggest that artificial silkworm food helped re-engineer the silk industry for the postwar era, and the work of developing synthetic food was part of a longer process of thinking about ways to reverse-engineer the making of silk itself in a way that clearly justified ongoing research of silkworm.

Lisa Onaga

Discussion

Artificial silkworm food would not completely replace mulberry in twentieth-century sericulture. Nonetheless, the time it did take to gain more widespread use widens our historical perspective for understanding its application. From its development in laboratories in the early 1960s to farms in the late 1970s, the remaking of mulberry—the leaves of which provided a perfect food for silkworms already—into an even more portable and time-defiant food represents how biological questions went hand in hand with the technocratic apparatus of postwar Japan. The development of artificial silkworm food is an intermediary for understanding the connection between the science of taste reception and palatability and the industrial fermentation of substances like MSG. Although intellectually motivated by questions about insect behavior, insect nutrition scientists ran a race against time toward the development of new artificial foods for silkworms. This sense of time was not just about corporate competition. The seasonal time of the mulberry plant in the temperate zone of Japan, along with changing land use in the postwar period, and dropping prices of cocoons that marked the seemingly fragile viability of Japan’s staying power in the silk market, all mediated the practical deployment of this special silkworm food. While much of what is popularly known of the uses of artificial silkworm food comes from a postwar context, a more precise way to consider the temporality of this research is as something that has taken place in a post-mulberry time—a dual notion of the mulberry’s seasonality and that of the uprooting of mulberry following the 1930s when falling cocoons prices spurred farmers to alter their strategies.

The research, policy, and commercial endeavors that went into formulating artificial silkworm food in Japan show that although the food was far from the silver bullet solution for making low-cost, high-yield silk, it holds importance for situating histories of biological research in their cultural contexts. Mulberry is still cultivated in Japan and elsewhere to maintain silkworm genebanks and university stocks, and to cultivate artisanal silk. Mulberry tea is neither common nor uncommon. Different types of artificial silkworm foods exist on the market today, some of which have soybean powder, others with crude mulberry. The story of artificial silkworm food and its odd coexistence with mulberry plants does not feed into a narrative of clear success or failure. Most important, the development of artificial food has diversified how people think about the purposes of silkworms.

Artificial silkworm food helped scientists conceptualize ways to rear silkworms out of season, or any time of year in a climate-controlled build-
ing. The biochemist Hayashiya Kenzo, who worked on developing antiseptic artificial food in order to rear "germless" silkworms in laboratory conditions, dreamed of "birudingu (building) sericulture," a riff on the borrowed word biru for Western-style brick-and-mortar or concrete multi-story structures.69 In addition to paving the way for the rearing of silkworms en masse in clean room laboratories where biomedical or veterinary substances are developed, and beyond the production of silk itself, silkworms are increasingly seen as a source of protein. The process of mail ordering "silkworm chow" in Europe, Japan, or the US is not at all extraordinary today. The main purposes of this food include feeding silkworms that are themselves fed as wiggly treats to pet reptiles. Artificial silkworm food has also been used to cultivate silkworms in space—not just to study silkworm behaviors in zero gravity, but also to develop a way to reliably supplement astronaut diets with a complete protein in the form of silkworm pupae, consumed in many parts of Asia.69 Artificial silkworm food must not be thought of as only a formula, based on a series of experiments attempting to determine equivalent, purified, substitutes for mulberry. By situating this aspect of silkworm science in both molecular and cultural contexts, we can understand how this thing—artificial food—is simultaneously a result of experimentation and engineering that was intended to re-engineer sericultural strategies in postwar Japan, and how it ultimately helped generate new uses for silkworms altogether.

9 * Cybernetics without the Cyborg: Biological Modernism(s) in Biomimetics and Biomimicry

RICHARD FADOK

What is cybernetics without the cyborg?1

This chapter opens with a question that strains the limits of enunciation.2 Which is to say: the figure of the cyborg has insinuated itself so thoroughly within our popular and scholarly discourses of cybernetics that it has proven nearly impossible to conceive of the sciences of control and communication without the amalgam of organism and machine that Manfred Clynes termed "cyborg"—the word itself a verbal amalgam, or portmanteau, of "cybernetic organism."3 Early cyborgs aspired toward the artificial evolution of the human, organic bodies mechanically augmented for anthropo-phobic environments, like outer space. The cyborg was nature remade.

Nearly impossible, because for the past six years, I have been conducting ethnographic research on biomimetics and biomimicry, two contemporary design paradigms in architecture and engineering that owe their existence to cybernetics, in the sense that they are its derivative or legacy discourses, but that traffic in non-cyborgian figures, ones which pose a different set of biopolitical questions about the relations between life, power, and knowledge in the twenty-first century.4

"A cyborg world is about the imposition of a grid of control on the planet," wrote Donna Haraway in "A Cyborg Manifesto," a laser-sighted work of feminist theory, which, like its subject matter of command-and-control, came to impose its own grid of intelligibility on the historiography of cybernetics.5 In the reticulated space she described, cybernetics, as represented by the "image of the cyborg," couples a scientific epistemology in which biological form appears as a control mechanism, with an engineering norm to control living organisms. The concept of control thus operates doubly, first to reduce organisms and machines to servomechanisms, then to plug them into ever-heightening systems of order. Life and technology, interior and exterior, form and norm—all become functions subordinate to the totalizing machinations of control. For Haraway, the cyborg promised feminists an ontology and politics. So too for the cyber-
34. Responsibilities for the Care and Disposition of Native Islanders of Rongelap and Utirik Atolls, 6 July 1954, NVO760692, NTAiLV.
37. A Radiological Survey of Rongelap Atoll, Marshall Islands, During 1954–1955, UWRL-42, Figure 2, NVO410695, NTAiLV. This data appears in Appendix One of Hines’ Proving Grounds, the documentary account of the lab’s work in the Pacific.
38. UWRL-42, 23, NTAiLV.
40. Ibid., 1–3.
41. Ibid., 1–3.
42. Land Crabs and Radioactive Fallout at Eniwetok Atoll, UWRL-50, May 27, 1957, 21–22, NVO407692, NTAiLV.
44. Repatriation of the Rongelap People, November 1957, 1–3, H&N Project Files.
45. Held to Comrad, 16 September 1958, Box 2, Folder 19, UWRLB.
46. Ibid.
47. Potassium and Cesium–137 in Birgus latro (Coconut Crab) Muscle Collected at Rongelap Atoll, UWRL-64, 15 January 1960, 7, NVO407657, NTAiLV.

Chapter 8


8. In the example of Nazi-era Germany's desire for self-sufficiency, academic breeders during the 1930s and 1940s developed meat-conscious foods that would maximize the fat and protein content of pigs. This feed consisted of a balanced mixture of fishmeal, soybean meal, rye, and potatoes. Tiago Sarniva, *Fascist Pigs: Technoscientific Organisms and the History of Fascism* (Cambridge, MA: MIT Press, 2016), 127–35.


10. While processed animal protein was prohibited as a feed source for ruminants according to the Food Regulation Act (adopted in 2015, applied in 2018), insect proteins are permitted, suggesting another decimation within the category of animals from which insects stand apart. Anu Liethenmaki-Uutela et al., "Insects as Food and Feeds: Laws of the European Union, United States, Canada, Mexico, Australia, and China," *European Food and Feed Law Review* 12, no. 1 (2017): 22–36.


14. It is tempting but difficult to equate the first half of the twentieth century in Japan as an explicit rise of fascism like that seen in Western countries. Assumptions about
Chapter 9

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7. For a fuller explanation of this duality, see Ronald Kline, The Cybernetics Moment: Why We Call Our Age the Information Age (Baltimore: Johns Hopkins University Press, 2015), ch. 6.
11. See N. Katherine Hayles, How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics (Chicago: University of Chicago Press, 1999). See also Kline, The Cybernetics Moment, for a detailed historical account of how Shannon’s theory of information was selected over Wiener’s as the lingua franca of cybernetics.
12. A prequise to the analogy of organisms and machines was the construction of the neuronal model of information processing by Warren McCulloch and Walter Pitts. Henceforth, organisms and machines became instantiations of a universal process. See Hayles, How We Became Posthuman; Kline, The Cybernetics Moment.
18. For critical analyses of these and other representations of cyborgs in American popular culture, from Marvel’s Wolverine to The Terminator series, see Gray, The Cyborg Handbook, especially part 4.
21. Kline, The Cybernetics Moment. I have retained the gendered pronoun “he” when referring to the subject of cybernetics to maintain the masculinist overtones that numerous authors have detected, and that pervades even Caidin’s Cyborg. See the prologue of Hayles, How We Became Posthuman.
28. My ethnographic data in this section and the next comes from fieldwork conducted on “bio-inspired design.” In the fall of 2014, I spent time with members of a biomimetics laboratory at MIT, which spanned six months intermittently. This consisted of attendance at weekly meetings; recorded and semi-structured interviews with the principal investigator and two graduate students who were then working on the project I studied (one hour each); and a literature review of their papers and dissertations (14 total). One graduate student asked to remain unnamed, whom I name “Anonymous.” Subsequently, I conducted four years of intermittent fieldwork with biomimicry designers at various sites across North America. In this paper, I introduce ethnographic data.


