Breeding from biotechnology: a look at the infrastructures behind the production of flood-resistant rice in India and Bangladesh

I. Introduction

Thanks to modern technology and advancements in agricultural breeding, developers at the International Rice Research Institute have found success in combating food insecurity in India and Bangladesh. Research and development efforts have been fruitful in breeding rice varieties with specific traits that enable them to withstand nature's powerful forces. One such rice variety goes by the name Swarna-Sub 1 and can withstand flooding for up to 15 days. This paper explores the infrastructures involved in the production process of this flood tolerant rice. I will first outline the historical and modern uses of the product, as a culinary and cultural staple. I will describe rice's significance in both social and economic terms. In this section I will also briefly describe the biotechnology called for in breeding flood-resistant rice so as to provide a basic understanding of the ambiguous term 'research and development.' Next I will define infrastructure and chronicle how human material and cultural infrastructures contribute to Swarna-Sub1's production. The following section defines ecostructure and describes the very ecostructures that support and contribute to rice production. This section included includes how rice production affects the environment, which leads to the final section focused on what we can do to continue supporting modern rice technology and institutions that work and advocate for food security across the globe.

II. Background

Rice dates back to 4000 BCE and is thought to have originated in SE Asia where today it is eaten 2-3 times a day by people of all classes and creeds (Katz, 2003: 190). Having spread to cultures outside this geographic location, due to its versatility and relative nutritional value, today, rice provides a cheap and nutritious food source for millions of people in both rural and urban communities around the world. In Asia alone there are roughly 250 million rice farms that produce over 90% of the world's rice supply. In India, rice is a staple food; in Hindi, rice translates to *Dhaniya* meaning "sustenance for the human race" (Katz, 2003: 190). Rice produced in SE Asia feeds more than half the world's population, but surprisingly most of this rice is consumed within 10 miles from the paddy farm where it was produced. A current problem for rice farmers in SE Asia is flooding, which can submerge rice for days or weeks resulting in damaged crops, and lower yields and profits for the rice farmer and their family. In Bangladesh, during the monsoon season, roads become inundated with water, farms are ruined, and farmers have to hope the rains end and their crops are able to withstand the downfall. During monsoon season, roadways become rivers; roughly 140 million people inhabit these monsoon-prone areas, of whom 70 million of them live on less than $1 a day. They are the areas with the highest concentration of poverty in the world. Losses in rice production can cost these communities over $1 billion a year in addition to the social and environmental costs that are often times overlooked (Ronald, 2008: 6). In Bangladesh, more than 20% of rice lands are flood-prone (Barclay, 2009: 28). How is the global community helping these communities in SE Asia, notably in India and Bangladesh? One solution comes from the International Rice Research Institute (IRRI), a research organization dedicated to stabilizing rice production around the world the ensure food security and continues livelihoods for local communities. Geneticists at IRRI worked 35 years, beginning in 1975, to develop a rice variety that can withstand submergence for up to 15 days and can be easily distributed to farmers in need. Using a technique called marker-assisted selection, scientists were able to identify the gene, in a low yielding rice variety named FR13A, responsible for the variety's natural ability to withstand floodwaters. The gene was named Sub1; using this new genetic information and advanced breeding techniques, researchers were eventually able to breed a traditional high yielding variety of rice called Swarna with FR13A, to create Swarna-Sub1, a high yielding, flood-tolerant variety of rice (Ronald, 2008: 10).

The most prominent processes involved in the production of Swarna-Sub1 are the research and development and on-site cultivation. In this paper, the production of Swarna-sub1 will be outlined by the material infrastructures that assist it's development in laboratories and greenhouses in America, the Philippines, and farms in India and Bangladesh as well as the cultural infrastructures responsible for the rice's initial conception and scientific undertaking. This paper will follow Swarna-Sub1 from the lab to the field, spending significant time outlining the ecological processes involved in the plant's growth such as photosynthesis and stem elongation, and the environmental factors, or ecostructures, that contribute to its success.

III. Human infrastructures

Infrastructure, in this paper, is defined as the man-made constructions and systems of distribution that allow for the flow of resources through communities.

Material infrastructure encompasses man-made buildings, pipes, tunnels, and transportation networks in addition to human-manipulated areas of land such as agriculture production sites. Working alongside material infrastructure, as the reasoning and intangible thoughts behind out actions and construction, is cultural infrastructure. Simply put, cultural infrastructure is defined as the ideas that contribute to the construction of material infrastructure; it is the reasoning behind our actions and rationale for creating what we do.

a. Material infrastructure

The production of flood-tolerant rice can be broken down into three main processes: research and development, plant growth, and distribution. In this paper, I will outline the structures and resources that allow proper functioning of these processes from the laboratories in California where the Sub1 gene was identified using marker-assisted selection, to the terraced paddies in India and Bangladesh. The production process of flood-tolerant rice is dissimilar to other manufactured goods in that the research and development of the specific rice variety, once completed, does not need to be repeated. Therefore, the material infrastructure and resources that went into the first step, identifying the flood-resistant gene, in the production process is no longer needed for the FR13A rice variety. I will focus primarily on these three aspects rather than the distribution from farm to plate. While there are many complex infrastructures at play in distributing rice to the people who eat it, what this paper aims to uncover are the hidden infrastructures behind the development of a genetically tinkered-with good that constitute the vague process of "research and development."

The process of realizing flood-resistant rice from conception to implementation on the farms of SE Asia required 35 years of research and development ("Scuba rice," 2010). The Research and development involved the physical research institutions including University of California Davis and their lab facilities, gene isolating equipment, and protective and conventional gear for the researchers. Marker-assisted selection is a "precision breeding" method where researchers isolate a gene in a species that can then be bred into another variety within that species. In this case, the gene responsible for flood-resistance was identified and isolated using highly specialized electronic equipment powered by energy from a California electric company, funneled to the labs through pipes and power lines. Specialized chemicals such as agarose gels were also used in this process, after being shipped to the laboratories from various locations across the country and delivered via postal services. Evaluation of crop breeding required trial growths in greenhouses with irrigated water supplied by a California water company (Collard, 2008: 557). Typical breeding programs grow thousands of individual plants meaning researchers gathered Swarna from its place of origin via planes and automobiles and the various skyways and roads that connect the rice field with the laboratory. Rice specimens were distributed via packaging factories and transportation infrastructures, from their place of origin in Southeast Asia to the laboratories and greenhouses (Barclay, 2009: 26). Further testing required rice to be sent to IRRI testing facilities in Los Banos, Philippines via airplane. At this site, the rice plants were monitored in greenhouses and fields. IRRI set up plots of land, manipulating the earth into proper rice paddy dimensions, then flooded the plots using water from one of four precious groundwater reserves, distributed by the Laguna Water District (Balota, 2014: 11). The seeds were planted in trays that were submerged in water when seedlings were 14-21 days old. When 50% of the plants appeared to be damaged or deceased, they were removed from submergence into a dry location in a greenhouse where they had a chance to recover. Testing equipment and human observations were instrumental in the trials. After 10-21 days in recovery, the plants were scored on survival by researchers (Septiningsih, 2008: 153). After observation of successful growth of the rice after submergence, the seeds were sent for testing and refinement to national organizations including the Bangladesh Rice Research Institute (BRRI) and the Central Rice Research Institute (CRRI) in Orissa and Narendra India using automobiles and airplanes (Barclay, 2009: 28). Before being sent to farms for personal and/or commercial growth, the seeds needed certification from the state seed-certification agencies in their respective countries of production (Barclay, 2009: 29). The flow of information through research papers and legal documents is key in moving the process forward to the farms in need. Some of the most prominent material infrastructures involved in all aspects of genetically modified rice production are the banking institutions that allow for the flow of money to these research institutions from non-profit organizations like the Bill and Melinda Gates Foundation, the UN Food and Agriculture Organization (FAO), and universities like the University of Cambridge. These nonprofit, governmental, and academic institutions are the backbone of the production process in addition to the systems of money transfer through snail mail or online connections ("Our Donors, 2016"). The donors, organizations, and banks are a constant need and underlying infrastructure responsible for the development and distribution of flood-resistant rice.

Finally, the rice underwent experiments on small farms in these areas in manipulated fields similar to the ones used for preliminary trials, out of the controlled context into the uncontrolled nature. After completion and success of the field trials and distribution of Sub1 rice to farmers in SE Asia, researchers from IRRI headquarters in the Philippines, the United States, and elsewhere flew to a central meeting location in SE Asia to take a tour of Asia's farms during a four years span from 2004-2008. This rice requires physical networks of airplanes and automobiles as well as knowledge networks that bring these researchers from different countries together to observe and take note on their genetically modified crop. The rice is harvested by manual labor and hand tools and processed by hard labor and animal power (Krock, 2000). Typically, rice grown on these small farms is either eaten on site by the farmer and their family or within 10 miles from where it was produced. The rice may, therefore, require the system of roads and fossil fuel powered trucks for it to be transported from the farm to towns where the rice will be distributed in the market.

b. Cultural infrastructure

The cultural infrastructures that support the production of FR rice and that gave way to its development and subsequent cultivation involve the values of the individuals who produce the rice, the beneficiaries of the crop, and the research institutions and individuals who promulgate the idea of ecological modernization through marker-assisted selection.

90% of the world's rice is grown and consumed in Asia. It is a staple crop for the majority of the population including 560 million poor. The cultural infrastructures that gave way to the creation of flood-resistant rice are ideas of food security, livelihoods for the impoverished, increased state-revenue, and high productivity. The ultimate driving force behind the creation of flood-resistant rice was the need for it from a human sustenance and cultural standpoint. According to the IRRI, "rice dies within days of complete submergence, resulting in total crop loss" (IRRI) and these losses negatively affect farmers in rural areas where alternate livelihoods are limited and poverty is high. According to Orissa farmer Bidhu Bhusan Raut, "better yielding is better living" (Barclay, 2009: 30). Rice has a great cultural significance in India and Bangladesh. As the oldest grain, rice makes an appearance in both dining and ritual practices. In some Indian cultures, rice is used as the first solid food a baby will eat. During memorial services, some Hindi families will prepare rice balls called *pinda* for the spirit of the deceased (Heitzman, 1996: 148). These two examples show that rice has cultural value as well as nutritional or economic value. While most rice is consumed within 10 miles from where it was produced, it is also an exported good, providing monetary value to the countries that produce it and adding another strand of information to what constitutes the cultural infrastructure underlying its production.

In Asia, approximately 20 million hectares of rice land are prone to flooding, meaning prone to crop failure, low yield, and hungry families ("Flood-Tolerant Rice Saves Farmers Livelihoods"). Between the 1960s and 1980s, parts of Asia underwent what is known as the Green Revolution, a revolution manifested in increased mechanization, fertilizer implementation, and technology application in an effort to combat food insecurity. The Green Revolution was a culmination of voices and thoughts on food security and increasing yields that led to the concrete research and development of flood-resistant rice technology (Heitzman, 1996: 33). During this time, the government of India made sure to highlight the cultural importance of this Green Revolution by subsidizing inputs such as fertilizer, fuel, and pesticides. The government also provided highly subsidized food grains to 65 million people living below-poverty households (“Rice and Food Security in Asia”). In the case of Swarna-Sub1, fertilizer and pesticides are not used as frequently, if at all, compared to other crops and regions that were targeted more so during the Green Revolution. It is for this reason that I will touch on, but not go in depth on the infrastructures and ecostructures connected to input use.

Because of industrial expansion, modernization, and human population concentration in country inlands, many farmers are pushed to the margins where they experience flooding, salinity, and other problems that come with the territory. Farmers used to have good water and soil quality, but not since being pushed from the inlands. (Barclay, 2009: 30). The IRRI works diligently in laboratories across in SE Asia and parts of Africa to counteract these less-than-perfect conditions. The International Rice Research Institute focuses, not only on flood-resistant rice, but the engineering of drought, pest, and disease resistant rice among its other work towards a more sustainable, equitable rice market. They value research and technology and see it as a tool for overcoming the negative externalities brought about by 21st century life and climate change. The IRRI and participating governments and organizations therefore uphold the ideals of ecological modernization, as defined by sociologists Gert Spaargaren and Arthur Mol (Spaargaren, 1992: 334). They see technology as a pathway to sustainability without compromising or decreasing production. As written in international magazine on rice research and development *Rice Today*, “The story of the *SUB1* research underscores the capacity of science to improve people’s lives” (Barclay, 2009: 29). They maintain that people can live their lives in the same ways simply by increasing efficiency with help of technology.

IV. Ecostructure

Ecostructures, as opposed to human infrastructures, refer to the natural ecological systems that influence and make possible, the production of a good. Ecostructures are omnipresence. They are the natural processes that differ from human-created material infrastructures that include watersheds and weather patterns among a myriad of other natural networks. Often, ecostructures and human infrastructures experience a clash due to human ignorance of how our actions affect the environment. This clash occurs because of the importance we place on our material goods and their production processes rather than our natural landscapes and their ecosystems. The ecostructure involved in the production process of flood-resistant rice is as explicit as it is such an engrained part of the production process, agriculture being so closely tied and dependent upon natural processes. In this section I examine several environmental processes involved in the production of rice from the hydrological cycles to the growth cycle of the rice plant. I will examine the environmental necessities for the production of this good as well as the environmental changes and degradation its production causes.

The ecostructures behind human infrastructures are often invisible or hidden, both literally – if a process happens underground or in a remote location – and socially – as the knowledge the producer hides from the consumer so as to make people less aware of the ecostructure and focus their attention on the finished product. With flood-resistant, and other agricultural practices, however, the ecostructure is so intrinsically intertwined with the material infrastructure that the two become almost indistinguishable. In other words, the ecostructures involved in the production of Swarna-Sub1 rice are transparent and easily recognizable. For instance, the majority of materials needed for the cultivation of rice come from the earth – soil, rain, and sun. Humans manipulate the land, turning open fields into carefully carved rice paddy's using modern machinery and human labor, but the ecosystems provide the services of photosynthesis and nutrient acquisition. The carved soil, with its essential biochemistry and microorganisms as an ecostructure, is transformed into an aspect of material infrastructure by its manipulation in such as way to distinguish itself from its natural state. There is an abstraction of nature into man-made infrastructure, but the elements of the ecostructure are still present and clearly visible. In the paragraphs that follow I will outline the ecostructures that contribute to rice's cultivation including photosynthesis, water networks, and micro plant-growth systems. I will then describe how climate change impacts rice production and the externalities produced from plant cultivation in terms of greenhouse gas production, land and ecosystem degradation, and input use.

Firstly, in regards to the research and development of flood-resistant rice, the ecostructures behind the scenes include the groundwater, rivers, and streams that bring water to the reservoir where it is distributed by water corporations to the laboratories and greenhouses where testing takes place. There are thousand-year-old ecostructures that compounded the earth into fossil fuels to then be extracted and transported to energy companies for distribution to power the lights and equipment of the researchers. A percentage of the energy, however, comes from a different ecostructure, one involving the natural power that a rushing river releases when confronted with a human constructed dam. These are just a few of the hidden ecostructures responsible for the proper functioning of the material infrastructures outlined previously. When it comes to farm trials and cultivation of flood-resistant rice, the ecostructures reveal themselves without in-depth inquiry. Photosynthesis is the most important and overarching ecostructure at work. Without photosynthesis, rice plants would have no source of food, and the rice industry, along with other agriculture, would cease to exist. The first act of photosynthesis takes place while growing the seedlings in the greenhouses to be planted later on in the paddies. Photosynthesis delivers the sun's energy to the hungry plants, providing energy in the form of sugar and allowing the plants to release oxygen into the atmosphere. Another equally important ecostructure is the water system and hydrological cycle. An overzealous hydrological cycle is, after all, the cause for flooding and main drive for the development of flood-tolerant rice. In India and Bangladesh, more than 5 million hectares are flooded per growing season. Monsoons and tidal movements inundate rice paddies with water from the oceans and rivers. Damage to traditional rice varieties occurs when the ecostructure of the field, in terms of topography and runoff sites, contributes to poor water drainage from the paddy to other points in the watershed, causing days or weeks of stagnate water ("Flood-Tolerant Rice Saves Farmers Livelihoods"). With Swarna-Sub1, rice withstands these waters, recovering after a slow drainage process.

Paddy rice is irrigated by diverted water systems (i.e. rivers, streams, groundwater reserves) into complex canals. Typically it takes 2,500 liters of water to produce 1kg of unmilled rice (Barclay, 2009: 27). In hilly areas, farmers use a technique called terracing, cutting into the hill to create a hierarchy or outcroppings, so that excess water in the fields flows from one outcropping to the next. This system of rice cultivation requires constant maintenance. At what point then, does it become a material infrastructure? The ground is manipulated in such a way to provide optimal rice growth and irrigation, but the water systems are still at play and have ultimate control (Krock, 2000).

In addition to the hydrological cycle and diversion of water systems for irrigation, the way water is used specifically by the rice plant's internal ecostructure is worth mentioning. The ecostructures that the plants house individually make up the greater success or failure of the farmer's rice yield and is therefore worth mentioning. Rice plants use and emit water through two processes, transpiration and evaporation. The water that is used directly by the rice plants as uptake and transport for soil nutrients and that leaves the plant to enter the global water cycle is called transpiration. Transpired water cannot be used again in the life cycle of the rice crop. Water that leaves the crop from the soil is referred to as evaporation and can also not be used again in the life cycle of the plant. Together, these two processes are referred to as Evapotranspiration and differ from other water loss due to percolation or runoff. In the case of percolation or runoff, water can potentially be used again in the same life cycle of the plant if it is collected by farmers or transferred to other water reserves (Boumon, 2009: 28). The ecostructures of the rice plant are complex and change from traditional rice varieties to crossbred varieties like FR13A.The Sub1 gene acts in opposition to typical deep-water varieties of rice in regards to conservation of energy during flooding. Typically, rice varieties will expend energy on elongation in order to peak its shoot above the floodwater. Deep-water varieties are able to elongate at rapid speeds whereas modern high-yielding varieties elongate at a slower pace, are not able to reach their head above the flood waters, and end up dying by submergence. When the Sub1 gene is activated however, the plant goes into a dormant state. It puts the energy gathered by photosynthesis, that would normally go into elongation, into reserves to be used for post-submergence recovery (Barclay, 2009: 27). The success of the rice ultimately depends on the ecostructures working in a harmonized manor to bring about optimal rain, sun, and nutrients to the crops.

With that said, the surrounding environment and climate of the rice paddy dramatically influence the outcome of rice yields. A rice paddy is not a controlled environment in a lab; it is subject to the changes, drastic and minimal, in weather conditions and animal activity on a daily basis. Rice cultivation changes with seasons, regions, and years. The local ecostructures of a specific region provide different inputs in terms of soil nutrients, sunlight, and ecosystem services than another region. For instance, an upland ecosystem provides highly aerated, dry soil and is rarely flooded whereas a rain fed lowland ecosystem is more prone to flooding and soil salinity due to its proximity to tidal areas (Matthias, 2004: 5). As another example of how a rice field's surrounding ecosystem and the ecostructures within it, we can look at dissolved oxygen. When looking at dissolved oxygen, a good indicator of water quality, we can see how the surrounding area affects the crops and how the rice plants respond. As the rice plants and other flora photosynthesize during the sunlight hours, releasing oxygen, and respire at night, absorbing oxygen, dissolved oxygen content changes, proliferating during the day, but becoming scarce at night. While this ebb and flow is a natural pattern engrained in crop growth ecostructures, the amount of oxygen becomes precarious when, say, farmers experience a week of heavy cloud cover or a significantly dark growing season. Ecosystem functions such as wind, rain, and animal activity also contribute to this change, causing turbidity, suspended fine soil and matter particles, which inhibit photosynthesis and lowers the content of dissolved oxygen available for the crops and microorganisms that require it for growth.

One of the most pressing and largest ecostructures involved with rice production is the global ecosystem in terms of climate change. The changing temperature of the Earth contributes to severe weather conditions such as drought, increased salinity, and flooding. During its life cycle, rice produces more greenhouse gases than any other major agricultural crop. (Stedman-Edwards: 6). Rice production releases greenhouse gases, namely carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), which contribute significantly to Earth's temperature rise. Heat trapping greenhouse gas emissions result from mechanical biological processes beneath the soil as well as interactions between organic and inorganic fertilizers with rice crops and the nutrients present in the soil (De Miranda, 2015: 2).

Not only do regional and global ecosystems affect the outcome of the crop, the farming practices associated with this crop affect the ecosystems they become a part of. "The most profound effects on the rice field flora may be those resulting from human intervention or farming practices" (Halwart, 2004: 9). Inputs like synthetic fertilizer and pesticides, that were heavily subsidized during the Green Revolution, affect soil nutrient content and pose threats to streams and groundwater reserves in terms of nutrient runoff. The late 1960s marked the beginning of Green Revolution and implementation of high-yielding varieties. Although fertilizer use has risen since the Revolution, input quantities remain relatively low in India, although it still depends on the state. In Punjab and Haryana, states that were heavily influenced by the Green Revolution, fertilizer use is around 200kg/ha, whereas fertilizer application reaches only 10-50kg/ha in other regions, regions where flood-resistant rice has found a home (“Rice and Food Security in Asia”).

During and after each planting season, soil erosion degrades the land and pollutes nearby water streams in the form of runoff. Soil fertility is depleted after the planting season due to high nutrient uptake and constant tilling of the earth as well as excessive use of inputs. Due to the manipulation of land, ecosystems that contain paddies also experience a loss of biodiversity (Stedman-Edwards: 6).

V. **Moving forward**

The production of flood-resistant rice was carried out as a solution to un-sustainable rice varieties and as a response to a changing global climate and local eco structural changes. While the production of this rice is complete, the IRRI and other rice research organizations are still working to develop rice with sought after traits that increase survival and better the livelihoods of both producer and consumer in marginal areas. Developing varieties of rice that can withstand extreme weather conditions, like flooding, is “one of the most important adaptation strategies,” when it comes to global climate change (“Rice and Food Security in Asia”). So what can we do, as global citizens? Support organizations like the International Rice Research Institute or other environmental organizations that work with IRRI (“Our Donors,” 2016). The research that organizations like IRRI conduct is expensive, but makes an impact. In addition to financial support, IRRI welcomes everyone from scientists to photographers to partake in securing global food sources; if you have a research and development skill or passion for food justice, you could provide valuable assistance to these rice projects. In some areas, the introduction of flood-tolerant rice has already increased yields by up to three tons per hectare; this number is only expected to rise as more farmers gain access to this variety ("Scuba rice," 2010).

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