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The technopolitics of agronomic knowledge and tropical(izing) vegetables in Brazil

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ABSTRACT

This article critically analyzes the social and political factors behind the advancement of technoscientific development in modern Brazilian agriculture. In the second half of the 20th century, Brazil underwent a rapid industrialization in the agricultural sector by more than doubling productivity in key global commodities and a widespread migration of people from rural to urban areas. Most observers point to the Brazilian Agricultural Research Corporation (Embrapa) as the technological engine that drove the industrialization of Brazilian agriculture. Existing approaches to analyze technoscientific development tend to overlook the role of the environment and individual scientists in enacting change. I argue that, especially in the case of agriculture, technoscientific development hinges on the extent to which the environment is disregarded or embraced by those who have the institutional support and capacity to innovate. To support my argument, I draw on two contrasting cases of crop development spearheaded by Embrapa scientists: the tropicalization of the carrot and participatory research on non-conventional vegetables. Through those two cases, the article demonstrates how the general and specific, the transnational and local, and the industrial and agroecological are all key contrasting factors for understanding technoscientific development in agriculture. This research is based on extensive interviews and participant observation at Embrapa's vegetable research center near Brasilia, Brazil.

1. Introduction

Few countries have experienced such a transformation in agriculture as quickly as Brazil. In just over fifty years, the country went from being a net importer of food to the world's largest agricultural exporter (Klein and Luna, 2018). Perhaps the most striking and well-publicized account of Brazilian agriculture focuses on the expansion of soybean plantations that stretch for thousands of hectares across the vast interior of the country. This process was made possible by the Brazilian government's support of public agricultural research on soil fertility and plant breeding to industrialize grain production previously not grown to scale at such low latitudes (Nehring, 2016; Márcio da Silva, 2018). Historical narratives, both within Brazil and abroad, place the Brazilian Agricultural Research Corporation, known by its Portuguese acronym Embrapa (*Empresa Brasileira de Pesquisa Agropecuária*), as the key protagonist in driving this agricultural transformation over such a short time (Cabral, 2006; Klein and Luna, 2018; Correa and Schmidt, 2014). Embrapa was established as a public company at the height of Brazil's military dictatorship in 1974. As a public company, it receives public funding but has relative institutional autonomy to determine the research agenda and to manage its internal affairs. As the Economist put it, the primary reason Brazil modernized agriculture so quickly can be summed up in three words: "Embrapa, Embrapa, Embrapa" (Economist, 2010).

The agricultural sector is vital for the Brazilian economy, representing approximately 7 % of GDP (IBGE, 2021) or up to just over a quarter of GDP when considering the upstream and downstream industries (e.g., inputs, processing) involved in agribusiness more generally (Cepea, 2021). Some of the most well-known cases of scientific research at Embrapa include the adaptation of large-scale soybean production in the tropics (Nehring, 2022; Almeida et al., 1999) and the use of imported grasses for cattle grazing (Márcio da Silva and Claudio de Majo, 2020; Nehring, 2023). Soybeans are arguably the most important agricultural crop as Brazil is the largest exporter of the crop in the world which amounts to an annual export value of over US$26 billion (Voora et al., 2020). Embrapa's longstanding relationship with large-scale agribusiness has been documented elsewhere (c.f., Mengel, 2015; Jardim, 2011); however, Embrapa has also served as a transformative technological driver in developing Brazil's domestic food production and consumption.

The case of Brazil is particularly interesting because Embrapa

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represents and supports what some commentators have called a "dual agricultural sector" (Milhorance de Castro, 2014). On the one hand, Brazilian agribusinesses are among the largest and most technologically advanced in the world. While on the other hand, over 70 percent of the country's farmers produce on relatively small, family-run farms that produce primarily for the domestic market (Schneider et al., 2011). Embrapa's institutional heritage has longstanding connections to the development of the country's agribusiness sector. Yet, at the same time, Embrapa maintains an active, if less publicized, research agenda with the family farm sector (Vilas-Boas et al., 2024).

This article focuses on one of Embrapa's iconic research centers, Embrapa-Vegetables, a research center near the national capital Brasilia that is emblematic of how scientific research shapes and is shaped by the country's dual agricultural sector. The goal of industrializing Brazilian agriculture remains an omnipresent force at the vegetables center, in line with the increasingly complex and globalized supply chains of these "non-traditional" commodities (Freidberg, 2004). However, whereas industrialized horticulture in much of the developing world is an export-oriented business, researchers at Embrapa-Vegetables are primarily concerned with the domestic market. This has allowed for the vegetables center to remain relevant for Brazilian farmers, even if Embrapa's research on vegetables tends to fly under the public radar. While the analysis that follows is specific to the Brazilian context, it indicates the broader importance of both national and transnational research networks in defining and determining how agricultural science influences the food we eat. In addition to the type and scope of research networks, I argue that environmental factors and the agency of individual scientists play a key role in shaping agricultural research agendas.

2. Background and methods

I draw on two different research projects at Embrapa-Vegetables – the tropicalization of the carrot and non-conventional tropical vegetables – to understand broader questions on the relationship between public scientists, the environment and diverse farmers. This research is part of a broader project on the history and institutional politics of Embrapa that involved 18 months of ethnographic fieldwork at 11 different Embrapa research centers and archival research in Brazil and the U.S. The qualitative data in this article is primarily derived from 24 key informant interviews at the Embrapa-Vegetables center and approximately five months of participant observation at the center and on farms with Embrapa-Vegetables researchers. These methods were used to understand the background and motivations of Embrapa researchers as well as the interactions between researchers and farmers. Interview data and field notes from participant observation were analyzed with Atlas.TI by coding for keywords related to the education, motivations and specific crops. Since this article is part of a larger research project, some interview and observation data were analyzed with other aims but included here for important background. Historical data was also collected from Embrapa's institutional archives in Brasília and from the National Agricultural Archives at Brazil's Ministry of Agriculture, Livestock and Supply (MAPA). Lastly, historical research materials from the Embrapa-Vegetables research center were collected via Embrapa's online library.

To any outsider, the setting of Embrapa-Vegetables wouldn't appear all that visibly different than public agricultural research institutes in India (Visvanathan, 1985), Tanzania (Geissler and Kelly, 2016) or even the notable CGIAR centers around the world (Byerlee and Lynam, 2020; Lorek, 2023). Like most research centers, the standardization of Embrapa aims to minimize its "Brazilianness". What is at once a research center situated within the ecological conditions of the surrounding Cerrado savannah and shaped by the social and political environment of Embrapa, is also a hub of transnational expertize. Most of the center's researchers work at multiple locations and scales – from farms and field plots to greenhouses and labs. Gaining an expertize in generalized knowledge across environments was at the heart of their formal education, one based on principles of scientific transferability and adaptability (Raj, 2007). A majority of Embrapa's early scientists in the 1970s and early 1980s were recruited upon completion of their undergraduate education. Embrapa sourced financing from USAID and the World Bank to fund sending their new recruits abroad for their post-graduate education (Nehring, 2022). It was in the soil and plant sciences departments, mostly at US land grant institutions, where Embrapa scientists learned the methods and materials that they would later apply in Brazilian agriculture. The deployment of Brazilian agronomists abroad also helped to develop transnational research networks to continue the exchange of germplasm for crop improvement and to receive US agronomists through collaborative research.

Research conducted at Embrapa-Vegetables rarely rises to the top of the company's many famed scientific achievements mentioned above. The theme of vegetables would also not seem to be necessarily representative of Embrapa's reputation as an agribusiness-friendly agency. Yet, Embrapa encompasses tremendous scientific, environmental and geographical diversity. Their network consists of 47 different research centers around the country that each focus on either a specific crop (e.g., soybeans), theme (e.g., agroenergy) or biome (e.g., Cerrado). Embrapa-Vegetables is a research center that encompasses a diversity of scientific practice and differentiated relationships with an array of agricultural producers in Brazil. Researchers there manage projects that range from tomato breeding for large-scale industrialized production to studying the economics of local food supply chains. In other words, while it is not necessarily representative of Embrapa's iconic public image (Cabral, 2020), it is illustrative of its diverse research agenda and of its differentiated relationships with stakeholders.

Public scientists, such as those at Embrapa, are hired to carry out the policy objectives of the state. How those objectives play out on the ground is shaped by the scientists – their disciplinary norms, methods and interests – and is embedded within the ecological and social contexts in which they work (Hess, 2016). Scientists at Embrapa use their expertize to shape not only agricultural practice but also the environment. The environment in this case is typically of secondary interest for research or, at a minimum, it is considered by Embrapa scientists to be a controllable factor. For example, the experimental plots at Embrapa-Vegetables occupy a "middle ground" between basic and applied research where soils are heavily fertilized, fields are irrigated and pests are controlled. Planting takes place at extremely small scales under these controlled conditions. For many vegetable varieties here, the plots are merely the next step in a series of experimental stages – from the lab to the greenhouse and then to the controlled fields where – hopefully one day – they make it to the farmer. But that isn't always the case. Localized ecosystems and producers can also be integral to research design. In other words, the politics of environmental knowledge can be both globally generalizable and geographically situated (Vandemeer, 2003).

2.1. *Tropical ecologies and the scientific knowledge*

The issue of scale and place becomes crucial when applying biological sciences to agriculture. Agricultural expertize from one crop or production system might not be directly applicable to another, depending on the relationship between the components and the context. In the case of bureaucratic knowledge of forests in Mexico, Mathews explains "officials silence opposition by claiming to speak for the state as a thing and by claiming to translate generalized knowledge to local contexts" (Mathews, 2011: 4). Political economy has dominated the social science literature on explaining how science shapes agricultural development, and on why particular technologies emerge and who controls them (*inter alia,* Busch and Lacy, 1983; Kloppenburg, 2005; Howard, 2009). Another approach by Possas et al. proposes to use "technological trajectories" (Possas et al., 1996), which is a convergence of actors and "problem areas" in the agricultural sector (see also Parayil, 2003). Both political economy and technological trajectories help to explain long-term paradigms (e.g., the Green Revolution) and structural drivers (e.g., intellectual property).

Another notable approach to analyze technoscientific development is “sociotechnical imaginaries”, which are defined as “collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology” (Jasanoff, 2015: 6.). Although originally applied to the case of nation-states, sociotechnical imaginaries have since been broadly used to understand how different groups of people or even single individuals promote technoscientific solutions to solve collective, societal issues. Multiple imaginaries can also exist within a given society or nation-state, but the power relations which those potential multiple imaginaries. Further, as is central in the cases that follow, there is no role for the material conditions in shaping how or why particular imaginaries are manifested. Taken together, political economy, technological trajectories and sociotechnical imaginaries fall short in explaining the role of the environment and the potentially differing interests of researchers, and how the relationship between the two might shape future sociotechnical change. As I argue in the case of Brazil, technoscientific development in agriculture hinges on the extent to which the environment is disregarded or embraced by those who have the institutional support and capacity to innovate.

In the case of agricultural research in Brazil, tropical ecologies entail both a symbolic and material difference for scientific research. Scientists at Embrapa's research centers have been lauded for their work in adapting temperate agricultural commodities to the tropics. The tropics, as a broad ecological-climatic qualifier, is even central to the company's identity, as it is with Brazil as a whole (Peard, 1999; Dunn, 2001). Their claim as the “world's leader in *tropical* agricultural technology” does important political work when seeking international collaborations, most notably under the banner of “South-South Cooperation” (Milhorance de Castro, 2014; Wolford and Nehring, 2015). While the category of “the tropics” can certainly apply to a set of common biological and climatic characteristics, the imaginary of the tropics also has also played a key role in rationalizing colonialism and centuries of racial violence (Wolford, 2021). It is in the tropics where plantations of the past and present are based on the so-called rational use of land that extracts value from the environment and exploits people of color, all in the name of progress (Raby, 2017). Botanical collections and agronomic research were, and continue to be, embedded within this extraction of wealth across space and time (c.f., Baber, 2016; Brockway, 2002; Pardey and Beintema, 2001; Vanloqueren and Baret, 2009).

Acknowledging the legacy of colonial accumulation is not to suggest that the scientific research at Embrapa doesn't rely on and contribute to a generalized understanding of tropical ecologies. As this article will show, researchers at Embrapa are not merely “adapting” agricultural commodities to the tropics. They are tropicalizing them. Their research focus of relocating crops to the tropics reordered the materiality of production by creating new “tropical” technologies based on the model of industrial agriculture. At the same time, research at Embrapa is also explicitly working to revitalize tropical crops as part of a broader project of centering ecologies in agricultural research and food systems. The two research cases highlighted in this article illustrate how the practice of scientific research at Embrapa is enabled by public financing and technologically adept farmers but shaped by the interests of scientists and the tropical ecologies in which they operate.

3. Results

3.1. Tropicalizing the carrot

The carrot was first introduced into the continent of South America by Portuguese colonists who came from the Azores in the 18th century. Azorean immigrants grew carrots in the more temperate climate of the Brazilian south where cool winters were necessary to induce flowering. Selection cycles led to several different landraces that exhibited some desirable characteristics for tropical adaptation, such as heat tolerance, orange root coloration, and resistance to root-rot nematodes and leaf blight (Simon et al., 2008). Outside of Southern Brazil, and outside of winter, if you could find a carrot in the country it was imported and therefore expensive. For example, in the early 1970s carrots were around $2.50/kg (Vilela and Borges, 2008). The carrot was not common to the Brazilian diet nor was it a part of its culinary patrimony. The researcher at Embrapa who is credited with adapting carrots to tropical climates grew up on a farm in the state of Minas Gerais, which is currently the epicenter of national carrot production. When growing up in the 1970s he said that he “had never even seen a carrot until I went to college”. That was all about to change.

The agronomic school of the University of São Paulo (ESALQ – *Escola Superior de Agricultura Luiz de Queiroz*) started a carrot research program in the 1950s. Researchers at ESALQ were mainly concerned with the *Alternaria* leaf blight that plagued carrots when planted in areas with high temperatures. They managed to breed two cultivars (‘Tropical’ and ‘Cenoura Nacional’) that showed resistance to the leaf blight but weren't the desired bright orange coloration (Costa et al., 1974). It wasn't until 1978 that ESALQ and Embrapa-Vegetables established an institutional agreement to further carrot research in the country. The carrot was selected by Embrapa because it is highly amenable to industrial production at scale, could serve as a nutritionally rich food for urban workers, and was a common research crop at U.S. universities, where many Embrapa researchers studied for their postgraduate education. These factors shaped the agenda of carrot research at Embrapa, where scientific research was mobilized to overcome the environmental barriers of the tropics for temperate crops.

One of Embrapa's researchers had actually been working on disease resistance for tomatoes and sweet potatoes prior to starting their PhD in the U.S in the early 1970s. Their superiors had all studied at the University of Wisconsin and helped arrange their application for Wisconsin's department of horticulture. According to them, “I moved to the carrot for my dissertation research because my [future] advisor came to Brazil and said, ‘you don't want to go to Wisconsin unless you study the carrot'” (personal interview, 10/11/2017). This network of researchers between the U.S. and Brazil initially worked on crops that were used in experimentation at their universities in the 1960s and 1970s. At that time, in places like Madison, Wisconsin; Ithaca, New York; and Urbana-Champaign, Illinois – common destinations for Embrapa scientists – horticultural research programs rarely focused on vegetables native to the tropics.

Researchers from the ESALQ-Embrapa cooperative project continued to rely on landraces that were still being grown in the South of Brazil. These carrot varieties were descendants of a French variety known as Nantes.[1] They then crossed Nantes with varieties from Japan and the U.S. to develop a new carrot that was both resistant to leaf blight and had a desirable color and shape. Some of the plant breeders that worked on the project were confused about why they were working on the carrot in Brazil. According to one, he was told by the head of the center that, “let's make a carrot that works in the summer, the French said it was impossible…but we can make it work.” Looking back on the project, he said “[I didn't understand] where the impact will be; who is going to produce it, and what is the goal? To produce more? Be insect resistant? Better [taste for] cooking?” (personal interview, 9/6/2017). The carrot breeding program at Embrapa was a top-down initiative, but it was also the

[1] Around two-thirds of all global carrot production is based on varieties based on Nantes (see Simon, 2000).

combined result of both institutional directives from Embrapa and the training of early researchers abroad.

Their breeding resulted in two new varieties – 'Brasilia[2]' and later 'Kuronon[3]' – which were distributed and promoted by extension services for free as a public good. The public good mandate of these early cultivars was central to the eventual proliferation of the carrot among producers, who had little to no experience with commercial carrot production. Government intervention in agricultural research is seen as crucial due to the scale of investment required, high economic risk, and long-term horizons of farming (Alston et al., 1998). Investments from the Brazilian state into Embrapa were driven by an interest in lowering food prices to minimize the cost of labor and ultimately undergird industrialization (see Alves, 1983). Vegetable productivity was clearly an important area of research for Embrapa in the eyes of the Brazilian state. However, carrot research in particular has its origins in the scientists' educational background and transnational networks.

Embrapa's research on the carrot was based on the appropriation of landraces grown for generations in southern Brazil and then crossed with imported varieties to achieve the desired qualities of heat resistance, an orange color and a conical shape. The research narrowed crop diversity in pursuit of the "ideal" tuber crop for Brazilian consumers and the environmental conditions of Brazilian agriculture. This process of producing "ideal" carrots was based on what Embrapa researchers considered important qualities from their experience abroad. In the tropics, producing carrots with these qualities necessarily involved the standardization and industrialization of carrot production. As in the case of soybeans, the acidic soils throughout Brazil required chemical inputs. The "tropicalization" of the Brazilian carrot therefore became an industrial process. It is a crop with high yields when soils are corrected for acidity and can be easily grown in rows to ease the application of pesticides, herbicides, and mechanized harvesting (Embrapa, 2004). Successfully growing a tropical carrot variety based on Embrapa's standards is intimately tied with the substantial use of industrial inputs by farmers who are adept at mechanized cultivation.

When asked what is holding back the geographical expansion of carrots in Brazil, one researcher said, "because in a region like [the states of] Goiás and Mato Grosso [in the west] there needs to be an expansion of mechanized cultivation" (personal interview, 3/12/2018). In other words, it is no longer the breeding of carrots holding back their expansion, but the availability and use of farm implements. This is precisely because of the type of carrot the scientists envisioned to be most desirable for Brazilian consumers and productive for Brazilian farmers.

Brazil produced 58,000 tons of carrots in 1978. National production exploded to over 780,000 tons by 2015. The planted area of the crop grew from just over 10 thousand hectares (ha) in 1980 to over 25 thousand ha in 2006; productivity more than doubled, from 14 kg/ha to 29.3 kg/ha. Carrot imports soon declined, from 90 tons to just over 20 (Vilela et al., 1997). Carrots are now ubiquitous in supermarkets, restaurants, and dinner tables; Brazilians today consume over 5 kg per person per year and the market price is now less than $.40/kg, a drop in $2.10/kg (Dossa and Fuchs, 2017). One of Embrapa's vegetable breeders claimed that Brazil has the "cheapest and most uniform carrots on the planet".

Carrots in Brazil are indeed uniform and plentiful. That was the primary objective when Embrapa launched the research program to tropicalize the crop. The transmission of the Nantes variety from France to Southern Brazil and then its transformation into 'Brasilia' and 'Kuronon' was all based on maintaining uniformity and improving productivity. Uniformity was considered by plant breeders to be an important characteristic based on consumer research conducted at produce markets in the Federal District of Brazil, where Embrapa –Vegetables is located (Onoyama et al., 2010). However, no such consumer studies had been carried out in the first decades of the carrot research program. Consequently, the first cultivar, 'Brasilia,' constitutes 75 percent of carrot production in the country. The consistent shape of the 'Brasilia' carrot not only aids in the harvesting but also in the processing for consumers. Its uniformity helps to minimize scraping during processing that can lead to waste, but it also makes cleaning and cutting easier as well as improving the shelf life (Lana, 2000). Embrapa's research made the carrot economically viable but environmentally destructive when grown in the tropics (Fig. 1).

The history of carrot research demonstrates the power of state science in the transformation of socio-material realities and in adapting new crops to tropical ecologies. Transplanting the carrot to the tropics was not solely a scientific leap in plant breeding as much as it was the combination of industrial inputs, mechanization, and effective research outreach. The tropics do present challenges – such as the leaf blight and an extended dry period – but this was a challenge whereby research treating every farm as a factory (Fitzgerald, 2010) could make almost any vegetable viable for production. Philip McMichael and Bové and Dufour have termed the corporatization and globalization of food as "food from nowhere" (McMichael, 2009; Bové and Dufour, 2001). In this case, public agricultural research conducted at Embrapa has demonstrated how it is possible to create crop varieties that will produce "food from anywhere."

Carrot breeding at Embrapa arose out of political interest to lower food costs for Brazilian labor and out of the scientific interest to adapt crops they (or their advisors) studied in universities abroad. These interests coalesced, according to one researcher at Embrapa-Vegetables, from "demands that didn't exist". In other words, there was no known demand from producers within Brazil to increase the productivity or expand the production of the carrot. Carrots were not unknown to the average Brazilian, but it wasn't common on their farms or forks. Once the research showed promise, the tropically adapted cultivars were integrated within the existing distribution network of seeds, and then decades later into the private sector for multiplication and sale. It worked as a "technological package" (Conde Aguiar, 1986) due to its ability to disconnect the "agricultural from those local specific elements"

Image 1. "Brasilia" and "Kuronan" Carrot Varieties at Embrapa-Vegetables Experimental Plot Photo by Author, October 11th, 2017.

[2] Brasilia originated from a cultivar that was brought to Brazil by Jesuit priests and multiplied in Viramão, Rio Grande do Sul and collected by researchers at UEPAE (Unidade de Execucao de Pesquisa de Ambito Estadual) in Brasilia in 1976. The cultivar was developed by selection process over four years and launched by Embrapa in 1981 (Embrapa, 1990).

[3] Kuronan was launched in 1983 by Embrapa and is a cross of Kuroda Gossun (Japanese – known for heat resistance and resistance to leaf blight) and Nantes (French and was grown in the south of Brazil during the coldest and driest months – strong cylindrical roots, high productivity) by Dr. Hiroshi Ikuta of ESALQ in 1970 (See Ikuta, and Vieira, 1983).

(Ruivenkamp, 2003).

The largest producer of carrot seeds in Brazil today is the Isla Seed Company, located in Rio Grande do Sul. Isla, a Brazilian company, has cornered the carrot seed market and its sale of 'Brasilia' carrots alone represented 70 % of the total national market (Isla Sementes, 2001). Almost all the bids for commercialization of Embrapa's carrot varieties go to Isla. According to one of the researchers at Embrapa-Vegetables, "after we made that jump [in productivity] with the carrot, it's very emblematic of the tropicalization of a material that comes from cold weather farming. And what Embrapa did was arrive to a certain point when the large seed industries dominate the market." He continued, "[Embrapa] should focus on things that don't have so much of an economic impact as a social one…it should take advantage of [research on] crops that are local, such as Non-Conventional Vegetables" (personal interview, 9/25/2017). Another example serves to demonstrate this alternate possibility.

3.2. Living seed banks: Revitalizing non-conventional food crops

The second case of Embrapa-Vegetables research is on non-conventional food crops, known in Brazil as PANCs, an acronym for non-conventional food plants (*Plantas Alimenticias Não Convencionais*). Researchers on this project are working with integrated cropping systems of vegetables that are native to the tropics. The research is materially based around what they call a "living" seed bank, which consists of a collection of PANCs cared for by Embrapa researchers at the Vegetables research center. The overall project is not being officially funded by Embrapa. Researchers who started and are involved with the project have their salaries paid by the company, but they don't have project-specific funding. Financing comes mostly from agreements with cooperatives that serve as both recipients and providers of PANCs. Most importantly, the research is primarily driven by the interests of the project's scientists to promote vegetables that are native to the tropics. It is a result of their vision but enacted by the participation with a broad set of stakeholders, some of which are introduced below.

PANCs research at Embrapa fits broadly within what are categorized globally as "underutilized" or "forgotten" crops. According to Williams and Haq (2002), just 30 crops provide 95 % of all food energy worldwide. Unsurprisingly, these 30 crops are also where a vast majority of financial and human resources are dedicated by agricultural research institutions. Funding for these crops worldwide has underpinned the development of infrastructure, such as seed banks, distribution networks, and public-private partnerships. For example, producing tropicalized carrots in Brazil was based on industrialization. To be economically viable and ecologically possible, it requires irrigation, drainage, fertilization, and pesticides (Marouelli et al., 2007). Almost by definition, "underutilized" crops are alternatives to globalized industrial agriculture. However, the science on underutilized crops has tended to not focus on the institutional drivers or role of the environment in explaining why they receive so little attention and funding.

Tropical ecologies are, in fact, a fundamental factor behind the very idea of a "living" seed bank. Recalcitrant seeds are most common in the tropics. Such seeds are not viable for *ex-situ* conservation, as they do not undergo maturation drying, and therefore cannot survive low-moisture and low-temperature environments (Pritchard, 2004; see also Umarani et al., 2015). There is still some debate about the precise classification of what species produce recalcitrant seeds as there is more of a spectrum of desiccation sensitivity (Barbedo, 2018). This means that while all plants in the "living" seed bank are not necessarily incompatible with ex-situ storage, doing so may require specific techniques. Therefore, the "living" seed bank proposes *in-situ* conservation based on participatory research. Specimens there are not stored in traditional sense of seed conservation that tries to preserve and to ensure duplication by intentionally removing them from the materiality of production (Curry, 2022). Rather, the project's scientists are continually sharing and collecting new varieties and crops throughout Brazil. When collected, the seeds are planted in the seed bank to then observe the different ways in which they can be co-beneficial to the other plants or bred for improvements based on the locales and interests of farmers all over the country.

The collection is continuously shifting as participating smallholders experiment with PANC crops recommended by the researchers, breed them, and then share some of their own varieties with the researchers who, in turn, continue with more plant breeding. The "living" seed bank serves as a participatory agricultural research hub; it is where research on PANCs begins, ends and starts all over again. The researchers in charge of the project completed their Ph.Ds. in Brazil and are building a research network mostly within Brazil. As the leader of the project told me, they are focusing on "pantropical plants" based on "the reality of the tropics", which runs counter to Embrapa's history of "tropicalizing" temperate crops. According to the researcher, their approach to PANCs starts from "a different way of thinking [instead of an] absolute industrialization of agriculture without a more 'tropical' vision". Their tropical vision is explicitly against the idea of an agriculture "based on altering the environment to be able to [continually] produce more…and an increasingly complex technological package of inputs" (personal interview, 06/12/2019) (Fig. 2).

One of their most popular crops is the Mandioquinha-salsa (*Arracacia xanthorrhiza*), which is known by several other names throughout South America such as *arracacha*, *racacha*, *apio criollo* in Spanish, or *mandioquinha* (little manioc) or *batata-baroa* (baroness potato) in Portuguese. Mandioquinha-salsa is native to the Andes, but it is increasingly being cultivated throughout the tropics, and especially in Latin America. This crop is in many ways like the carrot – it is high in vitamin A, calcium, and protein (see Hermann, 1997). Yet, scientific research on this crop in Brazil is relatively new and is considered "alternative" with little institutional interest from Embrapa or other public research agencies. The crop is widely known by Brazilians and is available at most farmers' markets but has only recently appeared on supermarket shelves and the urban "foodie" scene. Like the carrot, Mandioquinha-salsa production in Brazil is almost exclusively for the domestic market.

The tropics as an environmental category is fundamental to PANCs research at Embrapa. All project researchers and participating farmers expressed a desire to embrace tropical ecologies as the productive base to improve research on vegetables and make a livelihood. Rather than a top-down or even a bottom-up approach, the project centers around the circulation of crops and knowledge that draws on the diversity of farmers and farm environments where PANCs are grown. For public research institutions, projects such as this one at Embrapa-Vegetables

Image 2. The "Non-Conventional Food Crops" Living Seed Bank at Embrapa-Vegetables Photo by author, June 17th, 2019.

demonstrate current niches that have potential to expand based on the specific socio-environmental conditions of existing underutilized crops. At the same time, such research programs do not need to be mutually exclusive with those such as the carrot. PANCs research and cultivation very often exist in conjunction with traditional crops that may or may not have different outlets, whether that is the market, self-consumption, or local and regional exchanges (e.g., CSA schemes).

Participant observation was conducted with two diverse farming systems involved with the PANCs project. One group of participating farmers is part of the Landless Workers' Movement (MST – *Movimento dos Trabalhadores sem Terra*), one of the largest rural social movements in the world (see Fernandes, 2022; Wolford, 2010). The other group consisted primarily of family farmers who sell to local markets (farmer's markets and restaurants) in Brasilia. Both groups differ significantly in not only the type of crops they plant, but also their household income, mechanization and access to the market. What they shared is an interest in growing native tropical plants.

MST settlements in the Federal District are in close proximity to the food markets in the city of Brasilia and its surrounding suburbs. Due to this proximity, most settlements in the area produce vegetable crops for the market and have recently started organizing Community Supported Agriculture (CSA) schemes. Families have been settling in the settlement visited for this research over the past 10 years, ever since the plot of land was deemed available for settlement by the National Institute of Colonization and Agrarian Reform (INCRA – *Instituto Nacional de Colonização e Reforma Agrária*). The settlers here grow a vast range of produce for self-consumption and for the market, such as manioc, corn, pineapples and tropical fruit trees. Only recently have they started participating in the project to receive new types of crops and to contribute towards the conservation and improvement of PANCs crops. Business is now thriving for them.

At one farm, the head of household had received an arrowroot from the PANCs project 2 years ago. She explained that she initially planted it just because it was free and was curious to see how it would grow. During the participant observation, the farmer showed an over 2 ha plot of Arrowroot (known in Brazil as *Araruta*). The arrowroot plot has become a key source of household consumption for her family and the keystone in her offerings for a local CSA. We then visited a neighboring farm. Here the farmer was intercropping PANCs and conventional crops in an agroforestry system. Rows of bananas provided shade and organic material for scattered corn, Mangarito (*Xanthosoma mafaffa Schott* – a small tropical potato), Vinagreira (*Hibiscus sabdariffa* – leafy vegetable), Moringa (*Moringa oleifera* – tree for tea, a nutritional supplement and fertilizer) and coffee. Across the entire property, the farmer estimated that they grew some 10–15 types of PANCs and has been increasing the number and scale of their production to serve the CSA. Both farmers explained that they have all but stopped using any chemical pesticides and are in the process of becoming certified organic. When we left each of the farms, they gladly provided us with the best performing crops they had grown, to be transplanted back in the living seed bank at the research center (Fig. 3).

Many of these crops they were familiar with, and they already had an existing demand for them (such as tomatoes and mangoes at the farmers' market). However, it was only in the last 3 years that they became involved with PANCs and the living seed bank. Their participation has exposed them to new crops – such as arrowroot or moringa – and has transformed them into both research participants and beneficiaries. Importantly, their exposure to the new crops also included access to information about how to plant them in relation and/or in rotation with other crops, how to harvest them and to prepare them for the market. They took this information and experimented with new techniques on other areas on their land that was based on their own availability of land, soil quality and the marketability of the crops. They began to offer these new crops to members of the CSA with information about their flavor, nutrition and use for consumers, and they increased the diversity of products for sale at the farmers' market. The scientists of the living seed bank also worked to ensure that the rural extension services from the Federal District (where Embrapa-Vegetables is located) would be able to give them advice on integrated farming techniques. However, there is no formal agreement between the project and rural extension, which leaves the Embrapa researchers often providing advice themselves when giving and/or collecting crops.

Image 3. Collecting Mangaritos (*Xanthosoma mafaffa Schott)* Photo by author, June 19th, 2019.

Our visits on another day consisted of those located at the bottom of the lush, mostly irrigated valley visible from the MST settlement. The farmers here support the local vegetable and fruit market of the Brasilia metropolitan area. Their production started with strawberries, but has since expanded to include carrots, herbs, tomatoes, and collard greens. To test the market, some of these farmers have also become active participants in the PANCs project. One, in particular, became curious about Mangarito, the tropical tuber mentioned above. The Mangarito is similar to a potato, but much smaller, and it has an orange flesh with a rich nutty flavor. This farmer explained that he can no longer plant enough Mangaritos. He gets calls daily from restaurants all over the country, and even neighboring countries, for his Mangaritos.

This particular farmer utilizes more conventional farming methods that consist of row planting, weed barriers (plastic wrap), and even chemical inputs for some of his crops. The outlet for his produce is almost exclusively for the market, which includes the local farmers' market but also extends throughout Brazil and just beyond to Argentina. The reach for his produce is due to the current market niche that has been growing for uncommon tropical food crops. We spent the day inspecting his fields and observing that the tubers were both the large and small root nodes that eventually turn into rich small potatoes. A few specimens were collected, again for transplantation back at the seed bank, and we headed back at the end of the day.

Each of these farms, and the diversity of vegetables grown on them, demonstrates new ways of revitalizing participatory research and public science in the tropics. As evidenced by the visit to one of the MST farmers, PANCs often serve distinct needs, whether for the market or household consumption, and can therefore be grown in conjunction with conventional crops. The case of PANCs research does show how the materiality scientific practice and agricultural production can be linked through one common goal of embracing local environments as the starting point.

4. Discussion

Public agricultural research has an important role to assist farmers in transitioning towards more sustainable practices that can feed the world – from the local scale to the global. Social science research on the contingencies of agricultural science and technology has tended to focus on the structural and long-term drivers. Framings such as "path dependency," "technological trajectories," "sociotechnical imaginaries," and "paradigms" are commonly used to explain the social and political forces behind knowledge production and technoscientific changes. However, in the case of agricultural sciences, I suggest that attention should also be paid to the role of environments and the researchers themselves in shaping the contingencies of scientific research and how producers' technical capacity (or lack thereof) ultimately determine the relative success of that research.

Research conducted at Embrapa-Vegetables provides lessons on how the relationship between the state, science and the environment shapes research agendas and why these agendas focus on the particular technologies and farmers to achieve intended results. Industrial carrot production wasn't the inevitable outcome of state interests to utilize research as a way to expand domestic food supply. Although the carrot research program drew on public funding, the carrot itself – and carrot production methods in the tropics – were the result of the researchers' interests, social networks and the availability of industrial-savvy producers. Therefore, both cases at Embrapa-Vegetables also demonstrate the degree to which scientists exhibit agency in selecting the crops and methods for the research projects. This is important to consider given the increasing interest in employing participatory methods, such as citizen science, in agricultural research which, among other objectives, aims to democratize knowledge production (see Ryan et al., 1891). Additionally, the turn to value the agency of nature in determining agricultural development outcomes (Comi, 2021) should also be considered in relation to the agency of humans in the innovation process.

This is where the "living" seed bank is provides a counter to most of the Embrapa model and its fame in industrializing agriculture, exemplified by the tropicalization of the carrot. Instead, it is research that relies on the active participation of producers as both providers and recipients of crops and crop varieties. It follows similar principles to citizen science, albeit more targeted towards small-scale producers. The project also defies official rules by having genetic material living and active; meaning it is constantly traveling outside of the company's official rules, by design. One of the company's policies includes the registration of all cultivars that enter and leave Embrapa centers. According to one of the PANCs researchers, this would involve "standardizing something that can't be standardized" and would likely lead to privatization of some of the cultivars. Following the Cultivar Protection Law in 1996, Embrapa now licenses its registered varieties via public calls[4] to the private sector, such as Isla Sementes with carrot seeds. Here again, the "living" seed bank is not only functional for the native tropical crops, but it also aims to improve and reproduce; the plants are native to the tropics and their selection is based on interactions with mostly small farmers. Whereas research on the carrot was about controlling for and standardizing genetic diversity, the heart of PANCs research is based on a web of unstandardized and integrated crop diversity in the tropics.

The examination of these research cases can be viewed as a window into the broader environmental politics of agricultural research worldwide. Agricultural innovation systems are increasingly turning more participatory, with calls for implementing approaches such as the "cocreation of knowledge" (Utter et al., 2021), "citizen science" (Ryan et al., 1891) and other forms of collaboration with food system stakeholders. However, less attention is being paid towards the role of the environment and the agency of scientists in shaping the outcomes of participatory research. Additionally, as exemplified by the two cases at Embrapa-Vegetables, the crop and cropping system play a crucial role in determining research methods and outcomes. As such, changes in institutional research policy towards more participatory methods will remain limited without broader changes in the research process, including crop selection, cropping systems and the environment in which food systems operate.

5. Conclusions

Both research cases at Embrapa-Vegetables could be considered more marginal in notoriety when compared to the globally recognized research that helped transform the Brazilian savannah into some of the largest and most competitive soybean farms and cattle ranches in the world. Yet, there are crucial differences between them that demonstrate the friction when scientific expertize travels from one country to another, from the lab to the field or across ecologies and epistemologies. This article illustrated how scientific expertize is developed and deployed by the state in drastically different ways and with distinct outcomes. It drew on in-depth ethnographic research conducted over more than a year. Ethnography has advantages for explaining how and why different ideas, meanings and values lead to different (and sometimes unexpected) outcomes (see Ofstehage, 2022). However, there are limitations in the scope and broader implications for applying these lessons to other contexts.

As agricultural research institutions worldwide continue to utilize their expertize for increasing agricultural productivity, additional research is needed to better explain the purpose and process behind such research agendas. In the context of Brazil, for example, there is a wealth of academic research on the political, social and environmental implications of rapid agricultural development in the country. However, more in-depth cases that explore the origins and methods of agricultural research in other contexts could expand our understanding of what kinds of foods are best equipped to feed the world and why. Uncovering national projects to feed countries are just a start.

Much like the case of the soybean in Brazil, the "tropicalized" carrot is framed as a result of a "national" institution utilizing ingenuity to overcome the environmental barriers present in tropical conditions. Instead of being celebrated as a triumph of adapting "modern" Western science, the narrative sold by Embrapa and the Brazilian government is that it was a triumph of "Brazilian Science". The carrot researcher at Embrapa even won the top prize for scientific research in Brazil - the "Prêmio Conrado Wessel," also known as the Brazilian Nobel Prize. But, although the science was certainly important, it was also enabled by the combination of political support for research, extension, and the producers themselves. Rather than just being a miracle of Brazilian scientific modernization, it was also a result of numerous other structural factors. As one former president of Embrapa once told me, in reference to agricultural modernization in Brazil as compared to the U.S., "what took you guys a century, we did in less than fifty years." This narrative, as told through the drastically different cases of carrot and PANCs research, is a story of how "modern" science is Brazilian too.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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[4] See: https://www.embrapa.br/en/editais-e-ofertas-publicas-para-licenciamento

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