INVESTIGATING THE CONNECTIONS BETWEEN INDUSTRIAL AGRICULTURE, PESTICIDE EXPOSURE, AND THE TIMING OF PUBERTY AMONG GIRLS IN RURAL COSTA RICA

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INVESTIGATING THE CONNECTIONS BETWEEN INDUSTRIAL AGRICULTURE, PESTICIDE EXPOSURE, AND THE TIMING OF PUBERTY AMONG GIRLS IN RURAL COSTA RICA

This dissertation research uses a biocultural approach to evaluate how rural environments characterized by industrial agriculture impact the lives and biologies of pre-pubertal and pubertal girls living in the rural region of Sarapiquí, Costa Rica. Industrial agriculture is associated with a reliance on agrochemicals, including toxic pesticides, and subsequent environmental contamination and exposure of nearby communities to pesticide drift. In addition, industrial agriculture, while may increase the production of monocrops, is intertwined with local food insecurity in which community members living in rural communities characterized by large-scale monocrop-agriculture do not have consistent access to safe, nutritious, and culturally relevant foods. Rather, industrial agriculture has replaced subsistence growing and reduces dietary diversity and access to a balanced and micronutrient-sufficient diet. Both food insecurity and exposure to synthetic organic pesticides during childhood and adolescence can have long-term consequences on growth, development, and health.

Through the three case studies presented, the dissertation asks three major questions (Figure 1): 1) what are the social, demographic, and spatial determinants of food insecurity and how does food insecurity influence diet, nutritional status, and the timing of puberty; 2) what are the household and spatial determinants of pesticide exposure; and 3) does variation in pesticide exposure contribute to variation in the age and risk of menarche when controlling for household demographics. A biocultural conceptual model combining evolutionary theoretical frameworks with cultural medical and engaged anthropological approaches was applied to answer these questions. Data stems from various quantitative and qualitative methods including survey, laboratory environmental chemistry, and ethnography. Primary data was collected through household visits during the months of February 2022 through June 2022. Participants completed a survey and interview questions related to sociodemographics, residential history, health, and perceptions of pesticide exposure. Diet was assessed using 24-hour recall and a food frequency questionnaire of foods that are commonly consumed in Costa Rica and are known to be locally produced with high levels of pesticides. The survey also included the Food Insecurity Experience Scale questionnaire, the Pubertal Development Scale questionnaire, and the Adverse Childhood Experiences questionnaire. Anthropometry, including weight, height, leg length, and triceps skinfold measurements were collected during household visits to measure nutritional status. Lastly, girls wore silicone wristbands consistently for three days to capture chemical exposure. Silicone wristbands are a novel and noninvasive method of measuring passive exposure to environmental organic chemicals.

Chapter one explores the prevalence of food insecurity across four different social-ecological contexts (SECs) within Sarapiquí, the contributions of household characteristics and socioeconomics to food insecurity, and the associations between food insecurity, diet, nutritional status, and the timing of pubertal landmarks among the dissertation sample. Since previous investigations have connected the timing of puberty to nutritional status and food insecurity, it was important to understand these characteristics among the sample (although preliminary analyses found neither were significant determinants of

pubertal timing among this sample). Furthermore, food insecurity during childhood and adolescence can have long-term consequences on growth, development, and health, and rural communities are particularly vulnerable due to isolation, poverty, limited transportation, and residential dispersion. The chapter highlights spatial inequalities within the region. Girls from rural agricultural and urban/peri-urban environments were most vulnerable to food insecurity compared to those from rural non-agricultural communities. Food insecurity was also associated with household income below the median (around $450/mo.), less fat consumption, and lower BMI z-scores, but was not associated with the timing of pubertal landmarks including thelarche, pubarche, and menarche. The chapter is the first, to our knowledge, to provide data on food insecurity among youth and their households in Sarapiquí. Additionally, it provides an overview of the social, economic, and ecological context of the dissertation research site and emphasizes important variation *within* the rural region related to access to resources and nutritional outcomes.

Chapter 2 provides an overview of the pesticides detected among a subsample (n = 54) using silicone wristbands-- a novel non-invasive method of measuring individual passive exposure to organic chemicals. It offers the first published data on individual pesticide exposure among humans in Sarapiquí and shows the social-ecological determinants of exposure. More specifically, the chapter tests assumptions about the determinants of pesticide exposure, such as proximity to forest and agricultural fields, finding connections between pesticide exposure and living in rural areas engaged in industrial agriculture. Proximity to pineapple fields, in particular, was most strongly predictive of exposure to current-use pesticides. The lack of associations with exposure and household characteristics paired with the wide dispersal of exposure to both current-use and organochlorine (legacy) pesticides highlights the extensive vulnerability of the population.

Chapter 3 centralizes the associations between pesticide exposure and age at menarche – the final pubertal event for biological females – while also assessing and controlling for the roles of sociodemographic and household characteristics within variation in age at menarche. Using linear regression among a subsample (n = 54), exposure to current-use fungicides and azoxystrobin, specifically, were related to earlier ages at menarche while total organochlorine pesticide concentrations were associated with later ages at menarche. Interestingly, the chapter shows that typical sociodemographic and nutritional variables, such as income and BMI, as well as maternal age at menarche were not related to menarche among the girls in this sample. Only large households (6+) predicted later menarche compared to households of four. The findings suggest that pubertal timing may be uniquely related to this specific context and/or may be driven by exposure to endocrine-disrupting pesticides and social cohesion. The chapter provides novel data on the timing of menarche among a small sample of girls in rural Costa Rica.

Combined, these three chapters illustrate the downstream impacts of large-scale industrial agriculture (and their related business models and agricultural practices) on local community members, specifically girls, in Sarapiquí, Costa Rica. While the context of the research is specific to Sarapiquí county, the results can be applied to similar rural areas that are characterized by industrial agribusinesses. The research bridges the broader social science interest in the impacts of absentee-owned industrial agriculture on local communities with the longstanding interest within biological anthropology in the timing and trajectory of puberty as an adaptive response to environmental pressures. Exploring the environmental contributions to variation in pubertal development and reproductive strategies allows for a better understanding of the embodiment of one's past and/or current environment such as one distinguished by industrial corporate-owned agriculture. Additionally, this dissertation uses novel methods and approaches, including the use of silicone wristbands as a noninvasive measure of personal passive chemical exposure, and contributes to the new interdisciplinary approach of studying the individual's unique "exposome"—total environmental exposures throughout one's lifetime—and its role in biological and disease outcomes (Lioy & Rappaport, 2011; O'Connell et al., 2014; Vrijheid, 2014; Wild, 2012b).

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INTRODUCTION

This dissertation aims to understand how rural environments characterized by conventional industrial agriculture indirectly and directly impact adolescent development using a biocultural analysis—one that evaluates the variation in, and interrelations among, sociocultural factors (e.g., access to resources), ecological aspects (e.g., landscape), and biological outcomes (e.g., nutritional status and the timing of puberty). More specifically, I explore the connections among local environments, food insecurity, pesticide exposure, and the timing of puberty among girls from a rural agricultural region of Costa Rica.

Because conventional agriculture fuels the larger globalized food system, it is necessary to understand the history, culture, and political economies underpinning the industrial food system and the inequity and injustices it produces, particularly for low-income and rural communities in developing countries. Among these injustices is relatively high environmental exposure to agrochemicals, including pesticides, and under protection fueled by power, greed, global demands, policies that favor yields and profits over environmental health and sustainability, and a lack of restrictions or observance of restrictive policies (Brown et al., 2020; Clapp, 2021; Galt, 2009, 2014; Gonzalez, 2015; Howe et al., 2024; Johnson, 2016; Saxton, 2021; Steingraber, 2010). Drawing from Mansfield and colleagues (2023), “pesticides can and should be understood as relationships that can only be fully apprehended through attention to embodied experience, and the ways that inequality and structural violence (often through processes that extend far beyond the site of application or exposure) mediate these experiences” (Mansfield et al., 2023). Furthermore, while rural agricultural communities/environments may often be geographically and socially isolated, they are not independent of larger socio-political-economic factors. The distance between the pineapple field in rural Costa Rica and the pineapple on the table of a middle-class family in Minnesota is solely geographical. Because of our concentrated global agrifood system, these settings are closely connected in every other aspect (Brown et al., 2020; Chapman, 2007; Gonzalez, 2015; M. K. Hendrickson, 2015; Kelloway & Miller, 2019; Maysels et al., 2023; McMichael, 2009; Robinson et al., 2021; Saitone & Sexton, 2017). For example, the operations of the pineapple industry – from the cultivation in the global south to the transportation to the north and the distribution to U.S. retailers – are largely controlled by one corporation (e.g., Dole, Del Monte)(Brown et al., 2020). Our food system has become a funnel – with few controlling the production, processing, and distribution of products for billions of consumers around the world. In sum, the levels of the food system supply chain (individual, household, local, regional, national, and global) are no longer linear nor separate (Clapp, 2021; M. Hendrickson et al., 2017; Keenan et al., 2023; Vorley, 2003).

It is necessary to underscore how the research questions and setting of this dissertation are connected to larger aspects of the globalized agrifood system to ensure a holistic perspective, which is central to anthropology, is achieved. I begin this dissertation with a brief overview of the history of the industrialization of agriculture, global reliance on pesticides, and food insecurity. Secondly, I address the critical role of scholars and researchers in highlighting the environmental and public health consequences of industrial agriculture and its use of toxic synthetic chemicals and endangerment of food sovereignty, the results of activist scholars and research efforts that have led to restrictive policies but also new pesticides and an ever-growing agrochemical market, and the role of developing areas within this market. This initial background provides a basis for understanding how macro (global/national) forces connect to, construct, and transform local social and ecological environments and thus directly impact human experiences and biologies; these impacts (food insecurity and pesticide exposure) are the outcomes of which this dissertation focuses.

Following this background, the introduction explains the rationale for the research and how the dissertation answers contemporary questions using a biocultural anthropological approach. I explain how the dissertation provides new insights related to the social and biological impacts of industrial agriculture among girls in Costa Rica. I detail the biocultural and conceptual model, followed by an overview of the research area. Finally, I present the objectives of the three case studies included and their roles within the larger dissertation aims. Note that for the introduction and conclusion, I use the first person “I”. However, the case studies presented in the three chapters use “we”. While I wrote these chapters and served as the principal investigator, the research design, analyses, and interpretation of the results were collaborative efforts among myself, my field research assistant, Costa Rican and U.S. colleagues, and IU advisors/committee members. Thus, it is necessary to present the data and findings in a tone that represents this collaborative work.

History of the global industrial food system and global pesticide complex

The roots of industrial agriculture and pesticide use are intertwined with the Industrial Revolution. The expansion of people and products via new technologies such as trains and large ships and the development of farming equipment and fossil fuel utilization created an opportunity to expand and intensify agriculture and with it, individual and national economies (Chu et al., 2022). Colonization fueled agricultural specialization for commodity export across the globe (Gonzalez, 2015). The social-economic shift to specialization growing of cash crops led to the reliance on imported foods in many developing countries, further growing the international food trade industry as well as the spread of pests and diseases (Gonzalez, 2015). Intensification, monocropping, and increased risks of crop disease motivated the use of agrochemicals (Gonzalez, 2015; Bertomeu-Sánchez, 2019).

Pesticides refer to agrochemicals applied to kill, control, or prevent pests that may harm the production of the crop (US EPA, n.d.). They encompass many classes of herbicides, insecticides/acaricides, nematicides, and fungicides/bactericides (Mansfield et al., 2023). They are designed to disrupt biological systems in their target organisms including hormone pathways, DNA synthesis, and organ function (Saxton, 2021). During the Industrial Revolution and early industrialization of agriculture in the late 1800s and early 1900s, producers made and used pesticides created by natural elements such as arsenic, copper, and nicotine (Bertomeu-Sánchez, 2019). It was biotechnological developments during World War II that initiated the wide use of *synthetic organic* chemicals to control pests.

During the war, synthetic organic chemicals were developed and utilized as a method of biowarfare – herbicides to kill enemy crops and food sources – but also to control and mitigate vector-borne diseases such as malaria in foreign countries using insecticides. Most of the insecticides utilized during the war were organochlorine pesticides including DDT, which was among the first to be employed for disease eradication during the war (Bertomeu-Sánchez, 2019). Because of DDT's success in killing vector insects, it was promoted by national and international public health organizations, including the World Health Organization, in Europe, Latin America, and Africa (Bertomeu-Sánchez, 2019). In the U.S., DDT was promoted in "urban sanitary campaigns and in households; it also prompted a technocratic discourse based on the dream of controlling nature (both pests and illnesses) by means of chemicals. The appeal of DDT favored the embrace of other synthetic pesticides along with the marginalization of other forms of pest control and the silencing of critical voices and precautionary tales." (Bertomeu-Sánchez, 2019).

The Second World War created the synthetic organic pesticide industry and global market. In the U.S., the war was used to market and sell newly created chemicals and surplus through advertisement campaigns such as "the war on pests" and "shoot to kill, protect your victory garden"(Bertomeu-Sánchez, 2019; Wassberg Johnson, 2021). These campaigns continued through the Cold War or "war on communism" and primarily pushed for residential and city use of pesticides. The development of the pesticide market/industry for large-scale agriculture, specifically, was part of the global adoption of industrial agriculture and role of synthetic agrochemicals in building a new industrial agrifood system known as the "green revolution" during the mid-20th century.

The green revolution refers to the global promotion of technology and monoculture of staple food items (i.e. cash crops) such as rice and wheat with the goal of increasing yields and "feeding the world" (Johnson, 2016; Gonzalez et al., 2006). The green revolution has long been connected to the pursuit of global food security, although the initial focus was to end hunger by improving access to calories and not necessarily a nutritious diet. The initiative involved pressures to use agrochemicals including fertilizers and pesticides to increase production (Johnson, 2016; Gonzalez et al., 2006; Mansfield et al., 2023). While the green revolution indeed increased food production, it led to the loss of sustainable and local foodways, less diverse diets, and a reliance on technology, including biotechnology (e.g., pesticides), referred to as the agricultural- or technological treadmill (Carolan, 2016; Johnson, 2016) that continues to impact contemporary producers globally. Producers must rely on technology to increase yields and remain competitive in a capitalist market economy and maintain their livelihoods (Carolan, 2016). Producers without the newest technology produce less, and therefore gain less profit, and are often left out of deals with larger distributors or retailers (Carolan, 2016). As a result, producers adopt technologies, such as harvesting or processing machinery and agrochemicals, to keep up (Carolan, 2016). Ultimately, this has led to what is known as the "pesticide treadmill", the continual need for more, new, and stronger pesticides or combinations as the result of pest resistance, monocropping (single-species agriculture that attracts specific pests and increases vulnerability to disease and losses), and the increasing need to produce more to meet the global demand and/or to remain profitable as overproduction reduces market prices (Bertomeu-Sánchez 2019; Mansfield et al., 2023). As a result of the pesticide treadmill, global pesticide utilization continues to increase (Shattuck, 2021; Shattuck et al., 2023). In the last thirty years, the value of the global pesticide market has doubled to more than $60 billion (Mansfield et al., 2023). The largest growth in pesticide-use intensity has occurred in lower-middle-income countries (Shattuck et al., 2023), and the Americas, specifically, import the highest quantities of pesticides annually (FAO, 2022).

The industrialization of agriculture and increasing specialization of staple cash crops has increased global access to cheap calories but has also decreased food security in that it has led to a reliance on poor-quality diets. Food security is defined as having consistent access to safe, nutritious, and culturally appropriate foods (USDA, 2018). Industrial agriculture has led to increasing exposure to harmful chemicals through food—limiting access to safe foods—a diet high in macronutrients, particularly carbohydrates, and low in micronutrients—lessoning access to nutritious foods—and a reliance on processed and imported foods that are cheaper and easier to access than traditional cultural food items—limiting the ability for groups to maintain their cultural foodways and access to culturally-appropriate foods, especially in urban and developed areas. In addition, industrial agriculture shifted economies across the world to commodity agriculture and largely reduced and endangered subsistence farming, leading to less self-sufficiency and increased reliance on the market economy and public subsidies/assistance (Sarkar et al., 2021; Gonzalez, 2015).

Critical pushback and changes within the pesticide industry

The rapid development of the pesticide industry and adoption of pesticide use for public health and agriculture was fueled by national [powerful] political and economic agendas that left no room or time for research investments related to the potential environmental and health hazards of these new synthetic organic chemicals. Rather, early pesticides were promoted as safe and beneficial, despite evidence to support these claims. It was not long, however, that scientists began to push back, provide data showing the harmful impacts of pesticide pollution, and advocate for regulatory policies. Among the most notable was Rachel Carson, a biologist and environmental activist whose book *Silent Spring* (1962) exposed the environmental damage of DDT including the killing of birds and aquatic species and the chemical's ability to accumulate in animal fat tissue (EPA, 2016a; Steingraber, 2010). She warned of pesticide misuse, persistence, and the potential to cause human cancer and death (Steingraber, 2010; EPA, 2016). Carson's book and advocacy are celebrated as the beginning of the environmental conservation movement and protection policies in the U.S. including setting the foundation for the birth of the U.S. Environmental Protection Agency in 1970 (EPA, 2016b; Steingraber, 2010).

The critiques by Carson and other scientists and activists eventually led to the ban of DDT in the U.S. in 1972, continual research of similar pesticides, and the banning of all organochlorine pesticides in the U.S. by the 1980s (EPA, n.d.-a, 2016a; Pops et al., 2013). Investigations eventually determined that organochlorine pesticides, among other synthetic organic chemicals, were highly persistent in the environment. These chemicals became known as persistent organic pollutants (POPs), or “forever chemicals”, and were eventually banned by the European Union Stockholm Convention in 2004 (Bertomeu-Sánchez, 2019; Castillo, n.d.; EPA, n.d.-b; Mansfield et al., 2023; Stockholm Convention, n.d.). Although they were phased out in the U.S. decades earlier, they continued to be developed and shipped to developing countries, mostly in the global South (Mansfield et al., 2023).

The banning of organochlorine pesticides, now often referred to as “legacy” pesticides, led to a reliance on alternatives, considered “current-use pesticides” (CUPs). Particularly, producers turned to organophosphate, carbamate, and pyrethroid pesticides, some of which are more acutely toxic than previous legacy pesticides like DDT but are less environmentally persistent (Bertomeu-Sánchez, 2019; Sánchez-Bayo, 2019). For example, organophosphates work by disrupting cholinesterase and causing cholinergic toxicity (Cotton et al., 2015). Today, many organophosphate and carbamate pesticides are also prohibited in the EU and other countries due to their health hazards. As such, new alternative pesticides continue to be developed that only slightly differ in their chemical construction compared to their banned predecessors (Bertomeu-Sánchez, 2019; Mansfield et al., 2023; Sarkar et al., 2021). These new current-use pesticides may be less acutely dangerous but still have physiological effects that increase disease risk such as carcinogenic, genotoxic, and endocrine-disrupting impacts, the latter of which has been associated with relatively low exposure levels (Mansfield et al., 2023).

Regulations have not completely kept legacy or more recently banned pesticides from the market. The generic pesticide industry has been a way for manufacturers and users to get around the bans of specific pesticides by adding additional ingredients or increasing additives which alters the product enough to be considered a different compound/solution/mixture but can increase the health risks associated with exposure (Sarkar et al., 2021). In addition, many of the strongest pesticides are compounds made of mixing various enantiomers. Selling independent ingredients separately allows consumers to create hazardous and possibly illegal (depending on context) pesticides by mixing the active ingredients—a market that keeps manufacturers and sellers profitable despite continuing increasing regulations (Mansfield et al., 2023; Sarkar et al., 2021; Shattuck et al., 2023).

Much of the contemporary documented use of banned pesticides including OCPs has been found in low- and middle-income countries, particularly Latin America (Mansfield et al., 2023; Sarkar et al., 2021; Shattuck et al., 2023). There is evidence of mislabeling and selling unlabeled pesticides in rural markets, local synthesis of dangerous chemicals by combining ingredients that remain on the market, and selling of generic pesticides similar to their banned counterparts (Mansfield et al., 2023; Sarkar et al., 2021; Shattuck et al., 2023). As a result, 99% of pesticide poisonings take place in developing countries (Bertomeu-Sánchez, 2019).

Rationale

Globally, agriculture has shifted from a system of producing and sustaining life to an industry of killing – not only of the "weeds", fungi, and insects that pose risks to the commodity but also of the organisms and natural environments nearby and the consumers at end of the food supply chain who consume hazardous chemical residues. Moreover, the heavy reliance on agrochemicals and monoculture has only increased vulnerability "'to blights, diseases, and droughts' for both the plants and the people who work them" (Saxton, 2021:75), continuing the pesticide treadmill. The emphasis on low prices for consumers and demand for products from across the world, such as the sweet Dole pineapple loved by the Minnesota family, has made consumers in the global north/west part of the production of structural harm and inequity in rural spaces in the developing global south. In these spaces, such as rural Costa Rica, multinational, often absentee-owned, agribusinesses take advantage of cheap land, lenient labor and wage laws, immigrant labor, free-trade policies that reduce overhead costs, and a less regulation and/or enforcement of local policies surrounding environmental protection and agrochemical use (Galt, 2009, 2014; Gonzalez, 2015; Johnson, 2016; Mansfield et al., 2023). It is this system paired with heavy market concentration in the global agrifood industry – where few companies own most of the land, operations, and distribution efforts of products—that fosters the continuation of inequality and structural violence—violence that is indirect and systematic (Farmer, 2004)-- so that consumers may have their foreign produce at low retail prices (Clapp, 2021; Keenan et al., 2023; McMichael, 2009; Saxton, 2021). Although structural harm is often referred to as "invisible", I push back against that assumption and instead argue that it is rather violence that is purposefully *ignored* or *overlooked* as the result of political, economic, and historical powers.

The unequal exposure to toxic pesticides through pesticide drift-- indirect exposure through dust, air, and water—among vulnerable community members is an example of structural violence that is not invisible but is very much ignored in many rural undeveloped spaces controlled by foreign wealthy agribusinesses (Saxton, 2021). This is especially relevant in developing areas/low-middle-income countries which may have fewer regulations, less enforcement/governance, and higher utilization rates of illegal or unregistered pesticides (Gonzalez, 2015; Mansfield et al., 2023; Shattuck et al., 2023). Chronic pesticide exposure is associated with increased risks of various diseases including neurotoxicity, reproductive disorders, metabolic diseases, cancer, asthma, and autoimmune disorders; and exposure during childhood can disrupt growth and development and further increase an individual's risk for diseases (Alvarado-Prado et al., 2022; Araya et al., 2016; Gore et al., 2015; Mata et al., 2019; Pathak et al., 2022; Saxton, 2021). Many contemporary-use pesticides are endocrine-disrupting, meaning they disrupt hormones in animals including humans (Gore et al., 2015; Mnif et al., 2011; Pironti et al., 2021). These include hormones involved in developmental processes like sexual maturation. As such, some pesticides have been connected to endocrine disorders, hormone-related diseases including cancers, fertility issues, and variation in the timing and rate of pubertal development (i.e., reproductive/sexual maturation)(for more on the biological impacts of endocrine-disrupting pesticides and associations with puberty, see section below titled "EDCs, Pesticides, and Puberty") (Attfield et al., 2019; Castiello et al., 2023; Castiello & Freire, 2021; Ozen et al., 2014).

Following Carson's efforts and the building of U.S. environmentalism, social scientists began to apply a broader critical approach; rather than attacking pesticides and use alone, they critiqued the larger industrialized global agri-food system and its role in environmental pollution, global inequality, and structural injustice (Galt et al., 2024; Mansfield et al., 2023). Some have focused on the topics of food sovereignty, highlighting the role of industrial agriculture in global and local food insecurity. Others have centered their investigations on international justice. For example, in the book *Circle of Poison: Pesticides and People in a Hungry World* (1981), Weir and Schapiro highlighted how pesticide bans and regulations in developed countries only increased the exportation, use of, and exposure to hazardous and persistent chemicals in the developing world (Weir and Shapiro, 1981; Mansfield et al., 2023). In response, the Pesticide Action Network was created along with UN initiatives to regulate pesticide trade (Mansfield et al., 2023).

Additional social scientists have explored the impacts of industrial agriculture on local economies and social health (Galt et al., 2024), including anthropologist Walter Goldschmidt and his foundational research on the impacts of industrial agriculture on “the quality of economic and social conditions within a community” in the U.S. (Peters, 2002:5). In the 1940s, Goldschmidt conducted field research among two farming communities in California. His work exposed inequities and local harm produced by the shift to industrial and corporate agriculture including a reliance on low-wage labor and the creation of two separated social classes (farm owners/businessmen/professionals vs. agricultural workers), increasing local poverty, and growing dependence on outside markets resulting in a decrease in the community’s self-sufficiency and resilience (Goldschmidt, 1978). In sum, Goldschmidt argued that industrial agriculture negatively impacts community well-being by reducing autonomy, equality, and local economies while simultaneously increasing health risks associated with the application of agrochemicals (Goldschmidt, 1978). His argument has become known as the "Goldschmidt hypothesis" in anthropology and sociology (Peters, 2002).

Since Goldschmidt's hypothesis, social scientists have intensely investigated and documented the sociocultural and economic dimensions of industrial agriculture and its impacts (Saxton, 2021; Peters, 2002) abroad and in the U.S. However, few have evaluated the impacts on human biology and health, despite a growing pesticide industry, increasing utilization and exposure, and expanded understanding of the biological effects and risks for humans. More specifically, little is understood about the impacts of industrial agriculture on local food security among rural agricultural communities considering the contemporary definition of food insecurity that includes safe, nutritious, and culturally appropriate foods and not just access to calories. In connection with food insecurity and nutrition, the interrelationships between rural environments characterized by industrial agriculture and pubertal development have been underexplored. Only a handful of investigations have evaluated the relationships between pesticide exposure, in particular, and sexual maturation among humans although the endocrine-disrupting effects of both modern and legacy pesticides are documented (Gore et al., 2015).

Using mixed-methods and holistic frameworks that underscore the connections among social-political-economic factors, local ecologies, and human biological outcomes, biocultural anthropologists are well situated and equipped to answer these under-investigated questions and create a bridge between the social and natural sciences. In this dissertation, I expand on Goldschmidt's hypothesis and adopt Carson's initial approach of connecting biology to sociocultural structures. I bring together the social science interest in the impacts of industrial agriculture on local communities with the biological anthropological interest in the environmental determinants of human biological variation. I also draw on medical biocultural anthropology and contemporary engaged anthropology for motivation, conceptual frameworks (see below section "titled Biocultural Framework and Conceptual Model"), and applied practices. Lastly, I centralize variation within rural spaces, an approach rarely utilized in research on rural livelihoods and experiences. Rather, most investigations are positioned within comparative urban versus rural models, especially in rural poverty research (Hooks et al., 2016). In their 2020 United Nations report, Samper and Gonzalez argued that due to recent sociocultural changes in Costa Rica, rural spaces can no longer be considered as simply in contrast with urban but demand new approaches that evaluate and understand rural communities as worthy of their independent story (Samper & González, 2020). They stress the importance of assessing and characterizing rural spaces in Costa Rica based on three dimensions: the economy and the environment, the functional flow of self-contained labor markets and interconnections to larger markets (e.g., urban centers), and the multivariate which refers to "differential access to services and resources associated with specific rights" (Samper & González, 2020:5). Using these dimensions, one may uncover variations in social-ecological contexts and lived experiences within a county (e.g., Sarapiquí), region, or territory. This dissertation responds to this call, highlights these differences in the rural county of Sarapiquí, and simultaneously provides original and valuable data on food insecurity, nutrition, puberty, and pesticide exposure among a highly understudied and vulnerable population.

Life History Theory

Genetic adaptations are not quick enough to deal with environmental changes or stressors that arise during an individual's lifetime (Kuzawa & Thayer, 2011; Smith et al., 2001). Thus, a large focus among biological anthropologists is phenotypic adaptation. Phenotypic adaptations are adjustments that can take place within one's life and even within minutes (Clutton-Brock & Harvey, 1979; Lasker, 1969; Stearns, 1992). They are possible thanks to *plasticity*—the ability of organisms to adjust physiologically, morphologically, epigenetically, or behaviorally in response to environmental stress (Lasker, 1969; Stinson et al., 2012). Phenotypic adaptations include acclimatization, developmental adaptation, and behavioral or cultural adaptations (Gould & Lewontin, 1979; Lasker, 1969).

Contemporary research shows that human adaptation to environmental pressures most commonly consists of phenotypical, non-genetic changes, and behavioral adjustments. Because many things influence phenotypes (e.g., diet, stress, illness) and behaviors (e.g., socioeconomics, education, culture) it is also difficult to measure whether a trait or behavior has an adaptive cause or is simply the result of environment. However, adaptive responses are very much contextual. Different groups and individuals face different environmental challenges. Thus, biological anthropologists must acknowledge and act to understand the local as well as sociocultural elements that motivate adaptive responses. In addition, different groups may adapt to the same stressor in different ways. For example, Cynthia Beall's work on high altitude adaptations has found that Andean's have adapted higher erythropoietin concentrations that increase hemoglobin and arterial oxygen content while Tibetans have higher blood flow and capillary density which increases diffusion and counteracts low arterial oxygen levels (Beall, 2007). Therefore, anthropologists cannot look for a set of universal adaptations. Instead, we must acknowledge and assess contextual variation in physical and social responses, which may or may not be effective and may or may not have costly long-term effects that mask their adaptive potential.

Acclimatization refers to adaptive responses that occur during one's lifetime to mitigate environmental risks such as malnutrition, disease, and climate change (Lasker, 1969; Leslie & Little, 2003; Thomas et al., 1989). A common example of acclimatization is the physiological response to cold. The immediate response includes the constriction of blood vessels which sends warm blood to the body's core, as well as the release of epinephrine and norepinephrine to stimulate rapid contraction of muscles (shivering)(Stinson et al., 2012). This raises one's metabolism and increases internal temperature. After five to ten days of cold, non-shivering thermogenesis is induced. Non-shivering thermogenesis is adaptive because it only modestly increases the metabolic rate mostly through the metabolism of brown adipose tissue. Thus, non-shivering thermogenesis is not energetically costly and keeps the body closer to homeostasis (Stinson et al., 2012).

Another form of acclimatization can occur during periods of growth and development. This is referred to as developmental adaptation (Lasker, 1969; Leslie & Little, 2003). Often, developmental adaptations involve metabolic trade-offs between growth and other physiological functions. Thus, developmental adaptations can be permanent and often include consequences (a "trade-off" involves both costs and benefits)(Hill, 1993; Stearns, 1992). A common form of developmental adaptation to nutritional, physiological, or psychosocial stress is growth stunting (Kuzawa & Thayer, 2011; Lasker, 1969; Snodgrass, 2012). Transferring metabolic resources that would have been used for linear growth to development or immune functioning will aid in the survival of an individual.

Long-term exposure to external stressors associated with harsh or toxic environments, from abrasive households to agricultural fields full of toxic synthetic chemicals, can also result in more permanent energetic trade-offs, or adaptations, especially when experienced during developmental periods. Plasticity allows individuals to adjust resource allocation based on intrinsic and extrinsic environmental cues such as one's health and nutritional status as well as local mortality risk, socioeconomic status, and perceived stress (Charnov, 1991; Hill, 1993; Snodgrass, 2012; Vitzthum, 2008). These trade-offs influence the timing of life events such as birth, puberty, and reproduction that require relatively substantial energetic investments. When an individual does not have sufficient energy to support these life history events as well as maintain other important processes such as growth and allostatic maintenance, then energetic trade-offs occur. Thus, we can employ evolutionary life history theory to understand how differences in the timing of these events act as an evolutionary adaptive response to environmental exposures.

Life history theory is based on the premise that life history stages occur by means of metabolic tradeoffs in which limited resources are allocated toward growth, reproduction, parental investment, maintenance, and survival (Bogin et al., 2007; Hill, 1993). The basis is that energy used for one purpose cannot be used for another. Life history strategies vary between individuals and are highly contextual. Therefore, life history theory helps us to understand how one's environment becomes embodied or "gets under the skin"(Krieger, 2005). The idea of "embodiment" refers to the biological effects of lived experience (Gravlee, 2009; Thayer & Non, 2015). Just as the genome is embodied within the cell, which is embodied within the organism, lived experiences are embodied within the social, cultural, physical, and ecological environment. The total environment throughout one's lifetime, which encompasses exposures to various externalities including synthetic chemicals and psychosocial stressors, is referred to as one's exposome (Wild, 2012). The ability to adjust one's metabolic investments and life history trajectory according to these environmental pressures is a mechanism for evolutionary change, helping to optimize survival and reproductive success given environmental constraints.

The timing of puberty is the result of gene-by-environmental interactions that operate through switch mechanisms in the hypothalamus-pituitary-gonadal axis (HPGA) (Ellis, 2013). Anthropologists have long been interested in the onset of puberty and specifically menarche—the first menstruation and typically last pubertal landmark for females--as flexible life history events that reflect environmental influences, such as psychosocial stress and nutrition, on reproductive strategies. Using life history, we can predict that when the immediate risk of mortality is high, individuals may delay or halt pubertal development and reproductive efforts so that metabolic resources may be used for survival to a later point when sufficient resources can be invested in reproduction (Jones, 2011; Promislow & Harvey, 1990; Vitzthum, 2008). In opposition, when there is a low possibility of surviving to reproduce successfully later in life (such as when facing high adult mortality or morbidity risks or short life expectancies), delaying reproduction would not be advantageous (Bogin et al., 2007; Jones, 2011; Promislow & Harvey, 1990). Instead, an individual may mature and reproduce earlier and more often to increase the probability that some offspring will survive to reproductive age.

Pubertal timing and menarche are just two examples of life history events that encompass important metabolic tradeoffs in which the allocation of limited resources is shifted from or toward growth, reproduction, parental investment, maintenance, and survival (Said-Mohamed et al., 2018). These trade-offs should result in an optimal age of reproduction (Vitzthum, 2008). However, trade-offs are just that – compromises within energetic decisions. Therefore, a shift in energetic allocation to reproduction and away from the development and maintenance of other important systems such as musculoskeletal, metabolic, neurological, and immune, can predispose individuals to poor health and disease risk especially when experienced at young ages. For example, early menarche has been connected to adolescent and adult-onset depression, behavioral problems, early sexual activity, growth stunting, obesity, type-2 diabetes, asthma, cardiovascular disease, and cancer (Ibitoye et al., 2017; Werneck et al., 2018).

Because earlier pubertal development among girls is associated with an array of immediate and long-term disease risks, scholars, public health researchers, and practitioners have dedicated much effort to understanding the causes of the secular decline in the age at pubertal onset and development events documented across populations over the last century (Eckert-Lind et al., 2020). The decline in pubertal age was initially attributed to improvements in food access and lower mortality risk, and it is well-documented that contemporary variation within populations correlates with differences in resource access, psychosocial stress, rearing environments, neighborhood location, and nutrition (Euling et al., 2008; Rogers, 2018). More recent declines in pubertal onset and increasing cases of precocious puberty (Eckert-Lind et al., 2020; Tung, 2021), however, may be the result of exposure to endocrine-disrupting chemicals (EDCs). EDCs impact the synthesis, breakdown, and receptor activity of steroid hormones, including those involved in the onset and rate of puberty (Ford et al., 2024; Gore et al., 2015). Puberty is stimulated when gonadotropin-releasing hormone (GnRH) is secreted from the hypothalamus in an unknown specific frequency and amplitude (Ellis, 2013). This stimulates the release of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), leading to the production of estradiol and follicular luteinization among girls (Abreu & Kaiser, 2016). Maturation and functioning of the HPGA axis, including the epigenetic stimulation of GnRH release, are influenced by environmental factors such as energy balance, mortality risk, and stress, as well as phenotypic characteristics such as nutritional status (Abreu & Kaiser, 2016). Menarche refers to the first menstruation and the last major pubertal development event for biological females. It is driven by an increase in estrogen and is used to mark the tempo of reproductive maturation among girls, with earlier menarche reflecting accelerated development (Witchel & Plant, 2020).

Contemporary humans live in environments drenched in synthetic organic chemicals, not only as the result of contemporary use but also due to the accumulation of synthetic organic chemicals in the environment since the dawn of industrialization nearly two centuries ago (Gore et al., 2015; Hamilton & Sarathy, 2018). Synthetic chemicals are an inevitable part of our exposome: an individual’s total environmental exposure load throughout the life course (i.e., accumulative life exposure load) (Goodrich et al., 2016; Vrijheid, 2014; Wild, 2012). They can no longer be ignored in research and health initiatives interested in the environmental contributions to biological variation and health and disease outcomes. Beyond direct endogenous impacts on hormones, consistent exposure to toxins requires constant detoxification and has been associated with inflammation and metabolic disruption--all of which are energetically costly (Gore et al., 2015; Gregoraszczuk & Ptak, 2013). Thus, a modern question has arisen for those interested in the timing of puberty -- what happens to developmental trajectories when one is exposed to chemicals that disrupt the hormonal and energetic drivers of life history events such as the onset of puberty?

I have adopted this new research question and interest in this dissertation, but only as part of a larger research agenda to understand how industrial agricultural environments in rural Costa Rica are embodiment and contribute to variation in the timing of puberty. I utilize a biocultural conceptual model (described below) to consider multiple systems: the global and regional industrial agrifood system, the local sociocultural, political, and ecological systems, and individual biologies and developmental systems. In this, I expand the definition of environmental exposures to not just toxic chemicals but to include social, household, and ecological factors which may or may not be “toxic”. Industrial agriculture is involved with social toxicities that may be embodied by those nearby such as poverty wages, environmental destruction, and geographic and social isolation of communities (Saxton, 2021). Individuals may be even more susceptible to harsh environmental circumstances in less developed areas where absentee-owned agribusinesses take advantage of political instability, low taxes, high unemployment rates, and immigration that create desperate employees, and less governance of agricultural practices such as the use of agrochemicals and violations of environmental protection regulations (e.g., contamination, encroachment of protected or private spaces) (Carazo Vargas, 2021; Hooks et al., 2016; Mansfield et al., 2023; Sarkar et al., 2021).

Girls living in rural communities in Costa Rica that are characterized by conventional industrial agriculture are predicted to be vulnerable to endocrine disruption through pesticide exposure due to their proximity to pesticide pollution as well as other environmental stressors associated with industrial agriculture such as poverty and food insecurity (Caravaca Rodríguez & Ugald Monteroe, 2020; Hooks et al., 2016). Despite this understanding, few studies have explored the connections among rural agricultural communities, food insecurity, pesticide exposure, and the timing of puberty among girls.

Food Insecurity, Industrial Agriculture, and Puberty

Food insecurity is defined as not having consistent access to safe and nutritious foods necessary for health and wellbeing (FAO, n.d.). Disproportionately impacting rural communities, food insecurity exists in tandem with industrial agriculture and monocropping, as specialization and cash crop production replace local production of subsistence foods and local economies (FAO et al., 2023). The food insecurity experience provides a unique opportunity to study the downstream effects of industrial agriculture and the environmental determinants of pubertal development because food insecurity is connected to both poor-quality diets and psychosocial stress. In middle- and high-income areas, food insecurity is often associated with overnutrition from consuming energy-dense but nutrient-poor diets consisting of ultra-processed foods, as processed foods are often less expensive than whole and nutritionally dense/diverse foods (FAO et al., 2023; Hadley & Crooks, 2012). On the other hand, in low-income countries and particularly rural spaces, food insecurity remains associated with undernutrition and hunger (Alaimo et al., 2020; FAO et al., 2023)3.

Reproductive maturation is energetically costly, especially since musculoskeletal growth and brain development continue throughout adolescence (Bogin, 1994; Reiches, 2019). Sufficient energetic resources are necessary to maintain healthy growth, development, and reproductive efforts such as the start and continuation of ovulation and subsequent menstruation. Undernutrition has therefore been connected to later pubertal development, as one may not have sufficient metabolic resources necessary for this costly developmental transition (Campisi et al., 2018). Overnutrition, on the other hand, is often associated with earlier puberty as energy stores signal sufficient resources to allow for earlier maturation and reproduction (Ellison, 2017; Villamor & Jansen, 2016). While psychosocial stress may be energetically costly, studies find an inverse association between stressful early life environments and pubertal timing. For example, harsh rearing environments during infancy and early childhood have predicted earlier age at menarche, the first menstrual cycle (Chisholm et al., 2016). Psychosocial stress can act as a cue for intrinsic mortality risk; in the context of high infant mortality or adult mortality risk, life history strategies may shift from long-term survival to investment in reproductive fitness (Chisholm et al., 2016).

Using life history theory, we can assume that when food insecurity is associated with undernutrition and/or exists concurrently with high juvenile mortality risk, available energy is allocated for somatic needs rather than for reproduction and menarche is delayed. On the other hand, when food insecurity associates with overnutrition and low extrinsic mortality risk, it is expected that females will have enough energy to sustain somatic needs as well as reproductive maturation and may begin puberty earlier. Previous investigations have shown that food insecurity is related to earlier menarche among girls in the U.S., particularly girls of color with higher BMI and higher allostatic load (chronic stress)(Burris et al., 2020; Burris & Wiley, 2021).

EDCs, Pesticides, and Puberty

While the genetic, nutritional, and psychosocial determinants of pubertal timing have been substantially investigated, we are just learning of the potential impacts of endocrine-disrupting chemicals within pubertal development. The endocrine system acts as an intersection between the body and the environment allowing organisms to respond to environmental changes by stimulating and regulating physiological actions and behaviors (Gore et al., 2015; Romero, 2004). Sex steroid hormones mediate the initiation of puberty and subsequent reproductive maturation (Ellis, 2013; Sanderson, 2006). Other steroid hormones such as glucocorticoids and mineralocorticoids are important in regulating allostasis and responding to stress (Bradshaw, 2007; Whirledge & Cidlowski, 2010). EDCs can disrupt the hormonal balance by targeting enzymes important for the synthesis and breakdown of steroid hormones, acting as steroid receptor antagonists or agonists, or altering the transcription of hormone receptors in different cell types (Abreu et al., 2013; Ford et al., 2024; Gore et al., 2015; Xu & Bo, 2022). Collectively, these impact the concentration of circulating hormones (Gore et al., 2015; Gregoraszczuk & Ptak, 2013). Additionally, EDCs can increase lipolysis and consequently body fat percentage (Gore et al., 2015); and many (including pesticides) are fat-soluble meaning girls with more body fat may experience a higher toxic load (Mnif et al., 2011).

Most pesticides have endocrine-disrupting properties that help in their goal to disrupt the biologies of target organisms such as weeds and insects (Saxton, 2021). Many can attach to and activate various hormone receptors including sex steroid hormones responsible for the onset of puberty and the rate of reproductive development (Gore et al., 2015; Marcu et al., 2023; Mnif et al., 2011). Largely based on non-human animal studies, endocrine-disrupting pesticide classes have been identified and include organochlorines, organophosphates, triazines, phenols, and azoles (Gore et al., 2015; Pathak et al., 2022). Many newer classes of pesticides have not yet been tested or findings are pending. The mechanism of endocrine disruption by pesticides seems to be highly variable across samples and pesticides where some have been found to be anti-androgenic, others inhibit estrogen receptors while some activate estrogen receptors, and sixteen show anti-mineralocorticoid activity (Arena et al., 2018; Hayes, 2005; Mnif et al., 2011; Pathak et al., 2022; Sanderson, 2006). Subsequently, the outcomes of exposure vary. For example, in some cases, exposure is related to reduced free estrogen while others find higher circulating estrogen associated with pesticide exposure (Castiello & Freire, 2021; Pathak et al., 2022; Pironti et al., 2021). Menarche, specifically, is stimulated by increasing estrogen secretion (Witchel & Plant, 2020).

Few investigations have explored the connections between pesticide exposure and sexual maturation among humans. Most are limited by their reliance on questionnaire data, such as maternal occupation during pregnancy and area of residency (e.g., near agriculture/on a farm) as proxies for pesticide exposure; as well as the use of cross-sectional sampling and focus on specific classes of pesticides or individual OCPs rather than assessing total exposure load and current-use individual pesticides that are used heavily within the context of the research area (Castiello & Freire, 2021). As such, the results have been inconclusive. A cross-sectional study among adolescents using urinary biomarkers found that the DEP metabolites, used to assess exposure to organophosphate pesticides, were associated with later pubertal development among both girls and boys (Croes et al., 2015). Assessments of pyrethroids in urine find potential relationships with accelerated puberty in boys but delayed sexual maturation in girls (Ye et al., 2017b, 2017a). Two longitudinal studies investigating outcomes of in-utero exposure to various pesticides document earlier pubertal development in girls but slower maturation among boys (Wohlfahrt-Veje et al., 2012, 2016). Exposure to specific OCPs including 2,5-dichlorophenol, 2,4- dichlorophenol, dichlorodiphenyldichlorethylene (DDE), and DDT in utero and among both pre-pubertal and adolescent girls have been associated with earlier ages at menarche (Buttke et al., 2012; Krstevska-Konstantinova et al., 2001; Ouyang et al., 2005; Vasiliu et al., 2004). However, a longitudinal study on the relationship between total OCP exposure, largely driven by DDE, and age at menarche found higher summed OCP concentrations (mostly DDE) were associated with later ages at menarche (Attfield et al., 2019).

Using life history theory, we can make predictions regarding total exposure load and pubertal timing. If exposure is high and consistent, resulting in continual physiological responses such as inflammation and detoxification, the exposure would be assumed to be energetically costly and related to delayed or slowed pubertal maturation. On the other hand, if exposure results in an increase in circulating sex steroids associated with female sexual development such as estradiol, we may predict earlier puberty triggered by endocrine disruption.

Biocultural Framework & Conceptual Model

This dissertation uses a biocultural approach incorporating evolutionary life history theory and the assessment of social and ecological factors to holistically evaluate the associations between rural environments characterized by industrial agriculture and the timing of puberty among girls. In other words, I assess how the implications of living in chemically toxic and resource-poor environments are embodied and expressed through changes in developmental trajectories. I meet these objectives by exploring the connections between living in an industrial agricultural community, food insecurity, and exposure to legacy (organochlorine) pesticides and current use pesticides, and subsequently measuring the contributions of food insecurity and pesticide exposure to variation in the timing of puberty. As such, this dissertation unites a longstanding topic of interest within biological anthropology – the evolutionary life history transition from juvenile growth to adult reproduction—with the emerging fields of environmental endocrinology, adolescent health, and agri-food systems studies.

The biocultural perspective acknowledges that humans are both organic and cultural beings. Thus, they must be studied and understood in light of biological processes such as evolution and adaptation as well as their sociocultural contexts (Stinson et al., 2012; Wiley, 1992; Dufour, Goodman, & Pelto, 2013). Researchers who adopt a biocultural framework seek to understand the coevolution and bidirectional relationships of culture and biology. This includes both the role of culture in shaping biology as well as the role that biology plays in forming cultural beliefs, norms, and behaviors (Wiley, 1992). The biocultural perspective notes that culture and biologies influence the environment (which is both abiotic and biotic), as well as how individuals respond to those environments. Thus, there is a constant dynamic interaction between individuals and their environments.

The biocultural model incorporates evolutionary theory to understand human variation, adaptation, and how environmental structures influence biologies and health (Pelto, Dufour, & Goodman, 2013; Wiley & Allen, 2020). The incorporation of sociocultural aspects into this understanding is what sets it apart from the traditional sciences of biology, anatomy, and biomedicine; and the use of evolutionary theory differentiates the subfield from those of public health and epidemiology.

As Figure 1 presents, the analysis is multifaceted, encompassing multiple layers in an attempt to understand the “glocal” (holistic) story—how macro factors associated with globalization paired with regional aspects construct and interact with local contexts and how these local contexts, and variation among them, influence individual environmental and biological outcomes (Hooks et al., 2016). In the case of this dissertation, these layers of analysis include both ultimate and proximate factors. In biocultural medical anthropology, ultimate factors refer to larger, more distal causes of biological/disease outcomes while proximate factors are nearer, more immediate causes and are often evaluated at the individual level. Through the use of a biocultural approach, the interrelations between the proximate and ultimate causes of biological outcomes can be brought to the surface. In this dissertation, I consider the following levels and their relative ultimate and proximate factors:

a) Macro (ultimate): global industrial agricultural food system
b) Regional (ultimate): industrial agricultural operations and related social, economic, and political factors
c) Local (ultimate/proximate): surrounding (nearby) social community, infrastructure, economies, natural ecologies (e.g., agricultural versus forest, climate), and pollutants (in the case of this dissertation, pesticides)
d) Individual (proximate): immediate social environment including household composition, food access/security, and diet, pesticide exposure, and biological environment and outcomes including genetics, nutritional status, and pubertal development (controlled

by hormones – the endocrine environment).

The biocultural model allows for multi-system and multi-layered investigations, moving the focus beyond a single chemical or behavior which has been the tradition in environmental and public health and toxicology research (Saxton, 2021). In addition, the context-specific approach that is central to anthropology and adopted here provides valuable regional and community-specific data that is often ignored in reports of pesticide use which tend to be measured and documented at a national level. This is especially relevant and important now as Costa Rica has done away with their pesticide registry system and state pesticide regulatory function (Mansfield et al., 2024), further obscuring the realities of pesticide use, pollution, and exposure among rural populations.

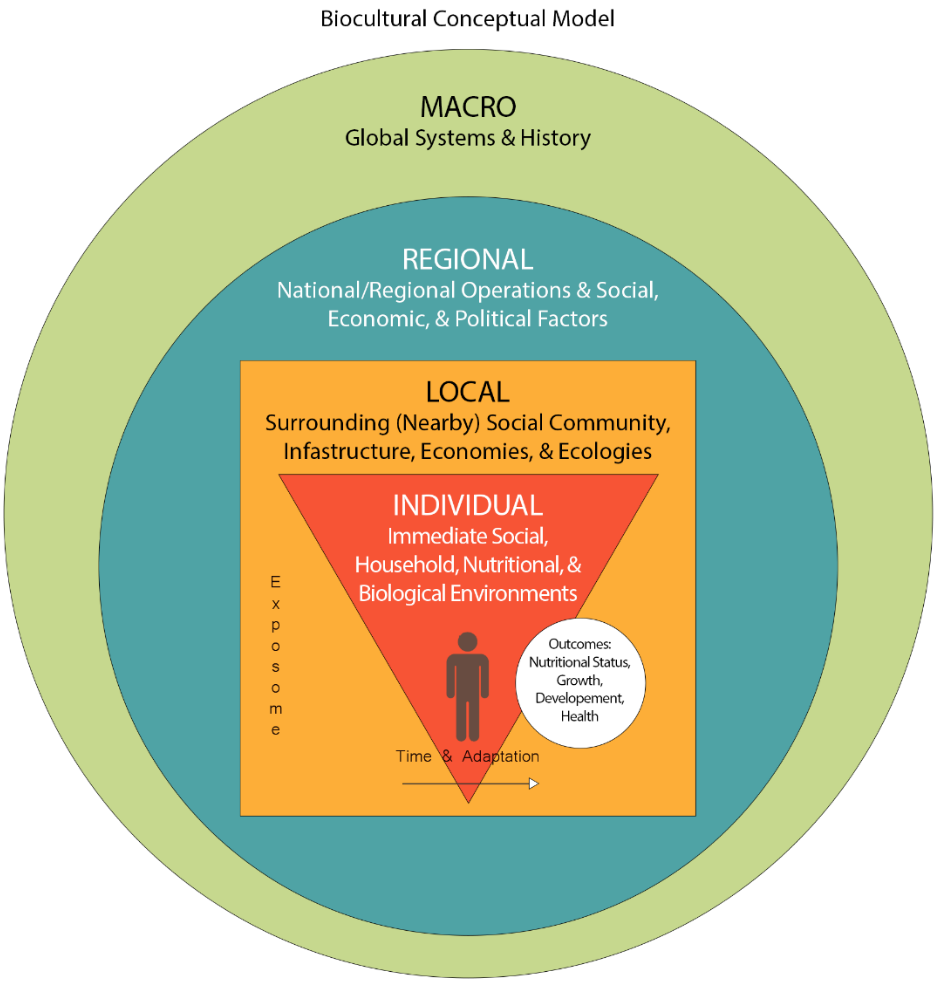

Figure 1 Diagram of the Biocultural Conceptual Model

Rural Environments and Costa Rica

In Costa Rica, the global industrial agri-food system maintains inequalities and injustices within rural areas, including halted socioeconomic development, low wages, food insecurity, occupational health violations, environmental contamination, land-grabbing and deforestation, and high exposure to agrochemicals including pesticides (Caravaca Rodríguez & Ugald Monteroe, 2020; Carazo Vargas, 2021; Guillén Araya, 2018; Jadin et al., 2016; León Sáenz &

Arroyo Blanco, 2018). Costa Rica uses some of the highest documented quantities of pesticides per hectare of land annually (Vargas Castro, 2021). According to a recent report by the United Nations Development Program, Costa Rica applies at least eight times the amount of pesticides to commodity crops compared to other nations (United Nations Development Program, 2022). Banana agriculture takes the lead, with more than 1.5 million recorded kgs applied in 2020 alone followed by grass grown for cow feed and pineapple which uses around 1 million kg of pesticides annually (Vargas Castro, 2021).

Figure 2 Example of a sign on the border of a banana plantation owned and operated by Dole. The sign indicates the use of agrochemicals and the prohibition of entrance by unauthorized individuals and vehicles.

The Context of Sarapiquí

This dissertation compares girls from rural [industrial] agricultural, rural nonagricultural, urban/peri-urban, and mosaic forest-agricultural environments in Sarapiquí County, Costa Rica. Sarapiquí is among the most rural counties in Costa Rica, where 89% of residents live in rural communities (Estrategia Integral de Prevención para la Seguridad Pública, 2019). Much of the ecological, sociocultural, and political-economic landscapes are largely constructed and controlled by large industrial agribusinesses (i.e., Dole, Del Monte, Chiquita). Because Sarapiquí borders southern Nicaragua, it is home to a large population of immigrants which account for

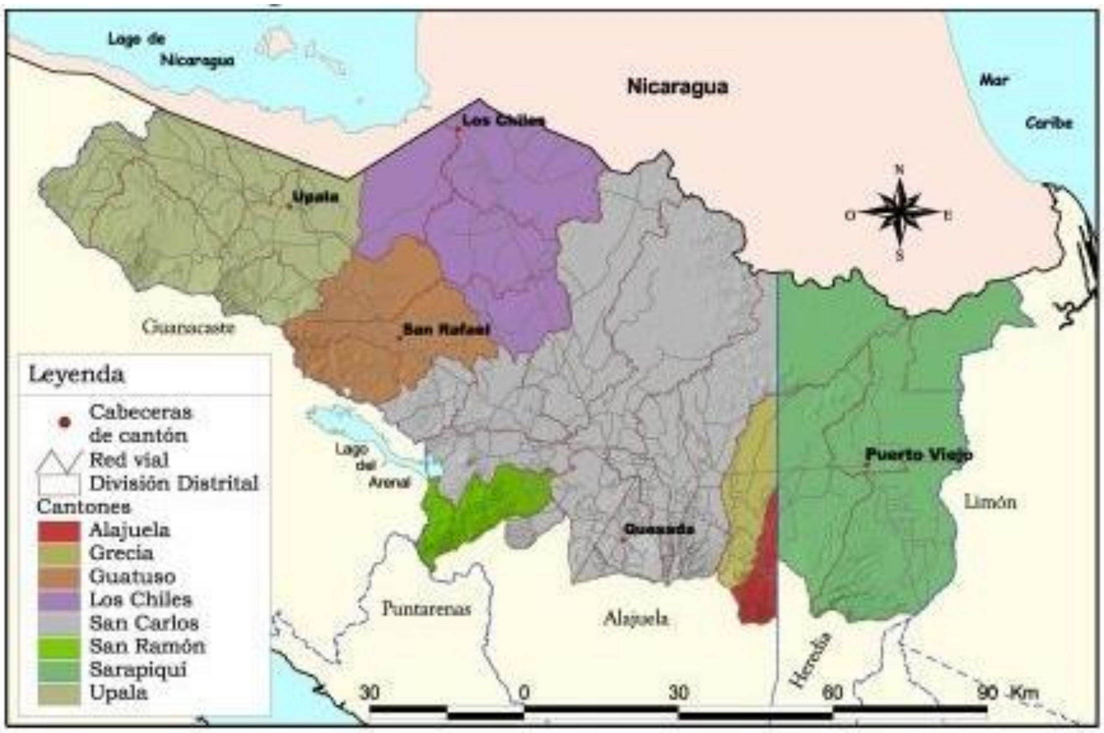

Figure 3 Map of the Huetar Norte region of Costa Rica. The eastern green section represents the county of Sarapiquí.

much of the agricultural workforce (INDER, 2015; INEC 2011, n.d.; Naranjo, 2014).

Around 40% of the population in Sarapiquí have monthly incomes below the rural poverty threshold (less than ₡99,537 colones or $191.27 USD), as determined by The National Institute of Statistics and Censuses (Estrategia Integral de Prevención para la Seguridad Pública, 2019; INEC, 2022). Higher rates of poverty are found among rural households and Nicaraguan immigrants (Estrategia Integral de Prevención para la Seguridad Pública, 2019; INDER, 2015). Around 27% of households considered "rural" by government planning agencies are impoverished and nearly 10% face extreme poverty. In the small urban centers of Sarapiquí, approximately 17% of households live in poverty with around 5% experiencing extreme poverty (INDER, 2015). The county is among the least developed (León Sáenz & Arroyo Blanco, 2018), and the province has the second-highest infant mortality rate in Costa Rica (INEC, 2022) (source: data from INEC, 2023 available at https://inec.cr/estadisticas-fuentes/encuestas/encuesta-nacional-hogares?filtertext=pobreza). Furthermore, the province has the highest prevalence of food insecurity (source: data from INEC, 2023 available at https://inec.cr/estadisticas-fuentes/encuestas/encuesta-nacional-hogares?filtertext=pobreza).

Many communities in Sarapiquí are isolated due to their rurality in what can be characterized as food deserts—places with little to no access to food, especially fresh and nutritious food, “due to the absence or low density of food entry points within a practical traveling distance” (FAO, 2017). Ironically, food insecurity and food deserts are juxtaposed against a rich agricultural landscape. A large part of the county is distinguished by large-scale, monoculture landscapes, particularly banana and pineapple plantations (Jadin et al., 2016; Municipalidad de Sarapiquí, 2022). Agriculture accounts for most of the county’s economy and 50% of jobs (Municipalidad de Sarapiquí, 2022). Most agribusinesses are owned and operated by foreign/multinational corporations that control a large share of the global food supply chain. The dominance of the monoculture industry, particularly banana and pineapple agribusinesses, is considered a factor contributing to the low level of economic development and sustained poverty in Sarapiquí. Scholars and activists argue for these agribusinesses, local socioeconomic development would be a threat to their business success which relies on cheap labor, relatedly poor education, and a lack of other job opportunities (León Sáenz & Arroyo Blanco, 2018).

While half of the landscape is characterized by large-scale monoculture fields, Sarapiquí is also home to the Braulio Carrillo National Park and various forest reserves and conservation areas. These forested spaces are mostly situated in the center of the county and in between agricultural sectors and/or large plantations. Therefore, Sarapiquí provides an opportune context to compare individuals and their lived experiences (including pesticide exposure) between highly different social-ecological landscapes. Moreover, its mixed landscape allows for the testing of longstanding assumptions about ecological environments and chemical exposure. For example, investigations often use distance/proximity as a proxy for exposure assuming that living far from agriculture will correlate with lower concentrations of pesticide exposure. In this dissertation (chapter 2), I test these assumptions.

Figure 4 A banana plantation in Sarapiquí. The raised pathway is used by workers who run bags of bananas ready for processing or packing across the field to the packing/processing site. The blue bags are insecticide bags placed around the fruit.

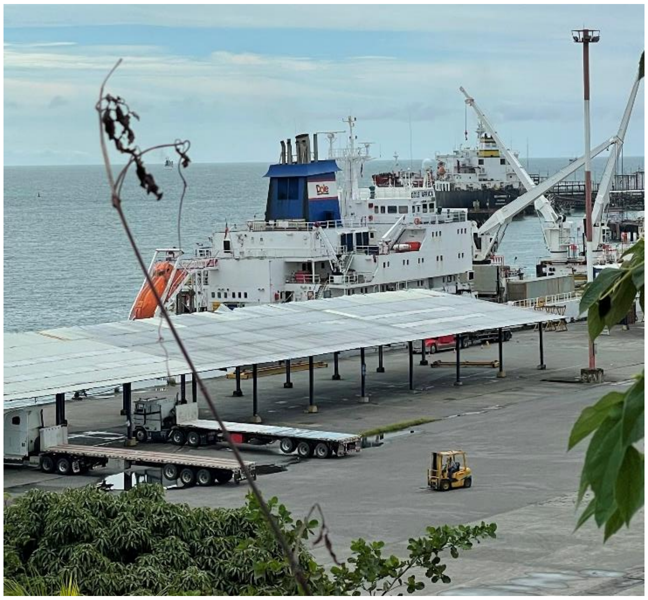

Figure 5 A port in Limón, Costa Rica where a Dole ship is docked.

Banana has a long history of being an important commodity for Costa Rica. The banana regions of Limón, the Caribbean province, were part of the initial agricultural initiatives of the Boston Fruit Company, later to become United Fruit Company known as "Yunai" among locals, in the late 19th and early 20th centuries (Chapman, 2007). Banana farms were implemented to fund a railroad that would connect the coastal port (shown in Figure 5) to the Central Valley with the goal of expediting coffee transportation to Europe. However, they quickly became one of the most successful food exports in the world as folks in the U.S. promptly favored the fruit for its exoticism and taste (Chapman, 2007); and this success fueled what would become known as the banana republic – the role of the United Fruit Company and later Chiquita in politics and war campaigns throughout Central and South America and the Caribbean, national and international economies, control within the agri-food supply chain, workers' rights violations, environmental contamination and intensive deforestation, and prevention of socioeconomic development in rural spaces in the developing world, such as Sarapiquí, Costa Rica. The famous book "Mamita Yunai" writes of the maltreatment, disease, pesticide poisoning, and tragedies that workers, primarily immigrants from Jamaica, China, and Italy, faced while working the banana plantations of Limón, Costa Rica during the early reign of the United Fruit Company (Fallas, 1975). For contemporary locals, these structural harms are not just something of the past. They continue today, particularly in relation to chemical exposure and disease and infertility, employee maltreatment, political and economic control, and environmental destruction and pollution (Brühl et al., 2023; Jadin et al., 2016; Mata et al., 2019; Ministerio de Agricultura y Ganaderia de Costa Rica, 2019; Shaver et al., 2015), including in Sarapiquí (from ethnographic research).

Figure 6 A monument in Alajuela, Costa Rica honoring the book Mamita Yunai.

In the 1960s, Sarapiquí became home to the second wave of the banana expansion after anti-trust laws forced the United Fruit Company to disperse (Guillén Araya, 2018). Nearly all the large-scale banana operations are situated on the eastern side of the county, bordering the Limón province, and are owned by multinational or foreign companies such as Del Monte, Dole, and Chiquita. Small towns reside within the plantations where many houses were constructed as part of the expansion for farm employees and their families.

Today, Costa Rica is the third-largest exporter of fresh banana in the world and the only country to have a registered geographical indication for banana (*Banano de Costa Rica – Corbana*, n.d.). The country is ranked first for the quantity of bananas produced per hectare of land (Vargas Céspedes et al., 2018). This lends perspective to the density of banana plantations and the relative level of labor necessary to maintain such expansive agriculture. In addition, the congestion of fruit plants in one space combined with humid conditions results in the heavy application of agrochemicals, as companies fear the ease and quickness of the spread of pests

Figure 7 A pineapple field in Sarapiquí, Costa Rica

and crop disease (Araya et al., 2016; Guillén Araya, 2018; Vargas Castro, 2021; Vargas Céspedes et al., 2018).

The pineapple agroindustry is a growing commodity in Sarapiquí and has become of great economic importance for the county, region, and country (Guillén Araya, 2018; León Sáenz & Arroyo Blanco, 2018). Although pineapple was only introduced as a commodity crop to Costa Rica in the 1990s and to Sarapiquí in the early 2000s, it currently accounts for more than 40% of Costa Rica's agricultural exports (Guillén Araya, 2018; León Sáenz & Arroyo Blanco, 2018; Vargas Céspedes et al., 2018). Costa Rica has quickly become the world's leader in fresh pineapple exportation dominating 85% of the U.S. pineapple market (Vargas Céspedes et al., 2018).

In Sarapiquí, pineapple plantations are scattered throughout, but the most expansive operations are on the northwest and eastern sides of the county. Reports show that pineapple expansion in Sarapiquí and the region, more largely, is a large factor underpinning deforestation and there have been growing complaints of infringement on and contamination of protected spaces by pineapple industries (Chavarría Cruz & Castro Duarte, 2021; Consejo Univesitario de la Universidad de Costa Rica, 2018).

Figure 8 A sign on the edge of a pineapple plantation in Sarapiquí, Costa Rica indicating the application of agrochemicals and the prohibition of entrance. The sign also includes a toxic warning. There are two men on motorcycles, potentially employees standing below the sign.

Figure 9 A pineapple field being sprayed with agrochemicals in Sarapiquí, Costa Rica.

Pineapple and banana agriculture are not the only pesticide-intensive crops in Sarapiquí. Monocultures of yuca, rice, palm, ornamental plants, and black pepper can also be found throughout the county (Vargas Castro, 2021; IRET, 2016). Pesticides are not only currently being added to the environment daily and at high levels, but they have a long history of use in the region(Araya et al., 2016; Guillén Araya, 2018). Beyond agricultural applications, insecticides historically and currently are applied at the national level to mitigate the risk of mosquito-borne diseases (Alvarado-Prado et al., 2022). They are also used for personal or community use and applied to households, businesses, and institutions (Alvarado-Prado et al., 2022). Many synthetic organic chemicals persist in the environment (Chaudhari et al., 2023). Thus, the combination of a long history of persistent pesticide use and current applications likely results in an accumulation of endocrine-disrupting chemicals in Sarapiquí.

Objectives

This dissertation research uses a biocultural approach to evaluate how rural environments characterized by industrial agriculture impact the lives and biologies of pre-pubertal and pubertal girls living in the rural region of Sarapiquí, Costa Rica. Through the three case studies presented, the dissertation asks three major questions (Figure 1): 1) what are the social, demographic, and spatial determinants of food insecurity and how does food insecurity influence diet, nutritional status, and the timing of pubertal landmarks; 2) what are the household and spatial determinants of pesticide exposure; and 3) does variation in pesticide exposure contribute to variation in the age and risk of menarche when controlling for household demographics. To answer these questions, a biocultural conceptual model combining quantitative and ethnographic methods was employed. Primary data was collected through household visits during the months of February 2022 through June 2022. Participants completed a survey and interview questions related to sociodemographics, residential history, health, and perceptions of pesticide exposure. Diet was assessed using 24-hour recall and a food frequency questionnaire of foods that are commonly consumed in Costa Rica and are known to be locally produced with high levels of pesticides. The survey also included the Food Insecurity Experience Scale questionnaire, the Pubertal Development Scale questionnaire, and the Adverse Childhood Experiences questionnaire. Anthropometry, including weight, height, leg length, and triceps skinfold measurements were collected during household visits to measure nutritional status. Lastly, girls wore silicone wristbands consistently for three days to capture chemical exposure.

Silicone wristbands are a novel and noninvasive method of measuring passive exposure to environmental organic chemicals. Silicone sequesters organic compounds including volatile and hydrophilic chemicals (O’Connell et al., 2014). Silicone wristbands have been validated as a credible inference of estimated respiratory and dermal exposure, but not necessarily for exposure through ingestion although investigations find positive correlations (Samon et al., 2022; Venier et al., 2018). The wristbands are worn by participants for a minimum of three days to sequester and later measure organic contaminants that individuals are exposed to through air or water (O’Connell et al., 2014).

The wristbands provide a noninvasive alternative for measuring personal exposure to chemicals compared to more invasive bio-sampling. The method also allows for the simultaneous capture and measure of numerous chemicals and total chemical load, whereas biosample analyses are often limited to one specific chemical or class, either by methodological- or cost restrictions, and cannot examine exposure mixtures or total exposure load (Samon et al., 2022). Plus, internal dose measures will not fully represent the mass balance of exposure to a compound (Samon et al., 2022). For anthropologists and human biologists interested in the environmental determinants of human variation including health and disease, it is important to attempt to measure and understand the exposome of individuals, or the total environmental exposures over one’s lifetime (Vrijheid, 2014). Silicone wristbands are a step in that direction, by providing a more representative measure of environmental pollutants and exposure load during the collection period (or

Figure 10 An example of the silicone wristbands used in the investigation.

wristband wear time).

The silicone wristbands have additional benefits when compared to other passive sampling techniques. For one, participants wear wristbands consistently, including when bathing, traveling, and sleeping. Therefore, silicone wristbands capture individualized exposure through various contexts (wherever the individual goes) and avenues including water, air, and touch (Donald et al., 2016; O'Connell et al., 2014; Samon et al., 2022; Venier et al., 2018) Individualized results are also valuable in showing interpersonal differences and variation both within and between households and communities. These described benefits are lacking in traditional passive samplers, such as air or water samplers, which are restricted to one specific location and one source of contamination (e.g., air or water)(Donald et al., 2016; O'Connell et al., 2014; Samon et al., 2022; Venier et al., 2018). These environmental sampling methods miss important spatial variation and are not valid for estimating personal exposure. Whereas mobile active passive sampling devices are more representative of personal contact with pollutants, they are costly and inconvenient [for participants] (Dixon et al., 2018; Samon et al., 2022).

Because the method is non-invasive and has a low participant burden, it is valuable for use in the field and appropriate across cultural and religious affiliations and vulnerable groups such as children and pregnant individuals. The wristbands do not restrict individual activity, making them an ethical option for measuring occupational exposures or for working individuals in general. Furthermore, the method is much more cost-efficient than biosampling, easy to transport and use in various field settings including across political borders, has a high participant retention rate, and the individualized results allow for more personal broader impacts and community engagement (Donald et al., 2016; Samon et al., 2022). Human biologists can use the findings to inform participants of their specific personal exposure levels, which may be a form a form empowerment through knowledge sharing. The results can shed light on variation between specific communities, regions, ecological settings, or participant groups, which may be useful in highlighting inequities and vulnerabilities of specific persons (Donald et al., 2016).

Following the understanding that ethnographic data is important to achieve a "fully developed and well-supported interpretation of the entire cultural scene," (Schensul & LeCompte, 2010:99) participant observation and informal ethnographic interviews were also utilized throughout the duration of the data collection period as well as during post-collection visits to Sarapiquí in 2023 and 2024. The ethnographic data is used to situate the findings of the case studies within the local context which includes the history, culture, and political economy of Sarapiquí and is largely connected to the presence and history of agribusiness and the globalization of agri-food systems. Therefore, the data presented in this dissertation is assessed and interpreted through a biocultural lens, merging approaches from biological and cultural anthropology while also incorporating methods from environmental science/toxicology/ecology.

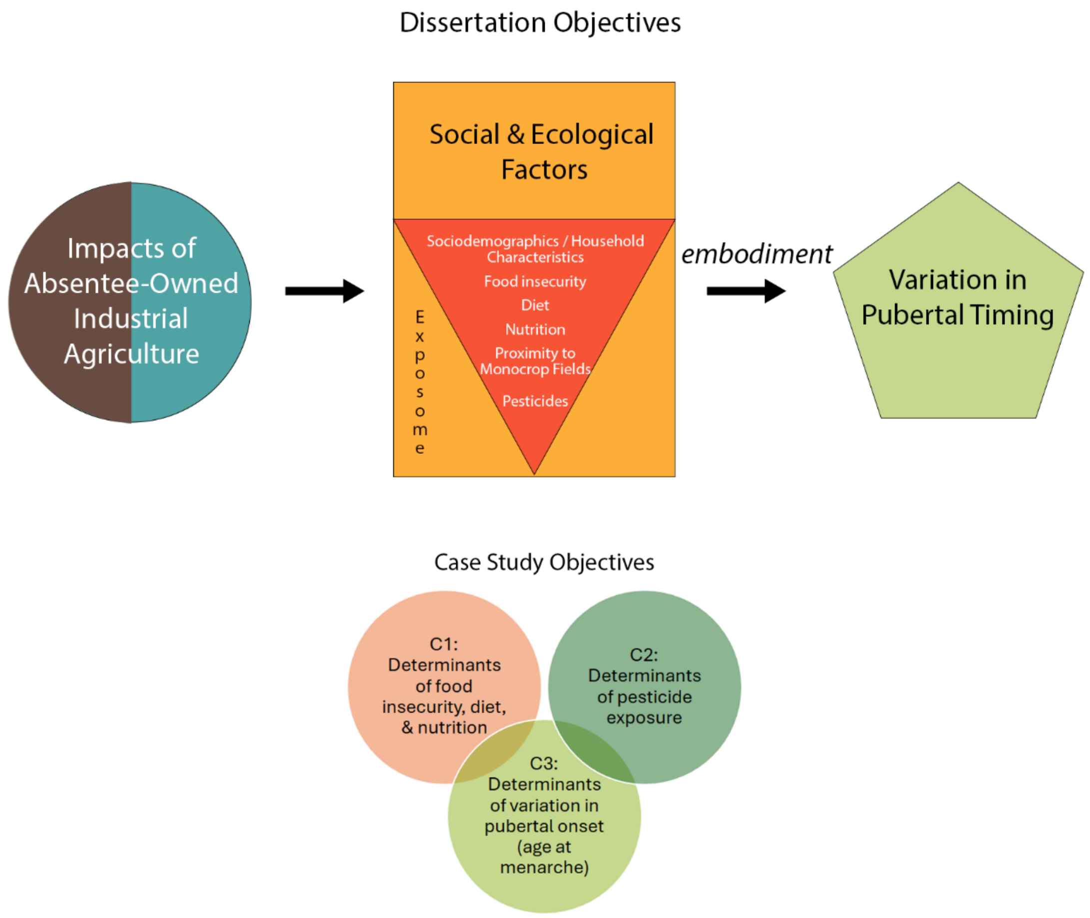

Figure 11 The above diagram represents the overall objectives of the dissertation research connecting to the biocultural conceptual model described in Figure 1. The main macro factor of interest is absentee-owned industrial agriculture, and the communities nearby/engaged with it. The local and individual contexts include social and ecological factors that make up one's exposome, and the biological outcome of interest is variation in pubertal timing as the result of the embodiment of the social and ecological factors. The circles below represent the objectives for each case study (chapter).

Case Studies/Chapters

Chapter one explores the prevalence of food insecurity across four different social-ecological contexts within Sarapiquí (rural agricultural, rural nonagricultural, urban/peri-urban, and mosaic (agricultural-forest), the contributions of household characteristics and socioeconomics to food insecurity, and the associations between food insecurity, diet, nutritional status, and puberty among the dissertation sample. Since previous investigations have connected the timing of puberty to nutritional status and food insecurity, it was important to understand these characteristics among the sample. Furthermore, food insecurity during childhood and adolescence can have long-term consequences on growth, development, and health, and rural communities are particularly vulnerable due to isolation, poverty, limited transportation, and residential dispersion. The chapter—a version of which is currently under revision for publication in *Scientific Reports*--highlights spatial inequalities within Sarapiquí associated with social and ecological environments including proximity to industrial agriculture. Girls from rural agricultural and urban/peri-urban environments were most vulnerable to food insecurity compared to those from rural non-agricultural communities. Food insecurity was also associated with household income below the median (around $450/mo.), less fat consumption, and lower BMI z-scores. The chapter is the first, to our knowledge, to provide data on food insecurity among youth and their households in Sarapiquí. Additionally, it provides an overview of the social, economic, and ecological context of the dissertation research site and emphasizes important variation *within* the rural region related to access to resources and nutritional outcomes.

Chapter 2 provides an overview of the pesticides detected among a subsample (n = 54) using silicone wristbands-- a novel non-invasive method of measuring individual passive exposure to organic chemicals. It offers the first published data on individual pesticide exposure among humans in Sarapiquí and shows the social-ecological determinants of exposure. More specifically, the chapter tests assumptions about the determinants of pesticide exposure, such as proximity to forest and agricultural fields, finding connections between pesticide exposure and living in rural areas engaged in industrial agriculture. Proximity to pineapple fields was most strongly predictive of exposure to current-use pesticides. The lack of associations with exposure and household characteristics paired with the wide dispersal of exposure to both current-use and organochlorine (legacy) pesticides highlights the extensiveness of the vulnerability of the population. The chapter will be submitted to the *Journal of Exposure Science and Environmental Epidemiology* this summer.

Chapter 3 centralizes the associations between pesticide exposure and age at menarche – the final pubertal event for biological females – while also assessing and controlling for the roles of sociodemographic and household characteristics within variation in age at menarche. Linear regression among a subsample (n = 54) indicated exposure to current-use fungicides and azoxystrobin, specifically, were related to earlier ages at menarche while total organochlorine pesticide concentrations were associated with later ages at menarche. Interestingly, the chapter shows that typical sociodemographic and nutritional variables, such as income and BMI, as well as maternal age at menarche were not related to menarche among the girls in this sample. Only large households (6+) predicted later menarche compared to households of four. The findings suggest that pubertal timing may be uniquely related to this specific context and/or may be driven by exposure to endocrine-disrupting pesticides and social cohesion. The chapter provides novel data on the timing of menarche among a small sample of girls in rural Costa Rica. The chapter will be submitted this month to the *Journal of Environmental Health Perspectives*.

Combined, these three chapters illuminate the negative downstream impacts of large-scale industrial agriculture (and their related business models and agricultural practices) on local community members, specifically girls, in Sarapiquí, Costa Rica. While the context of the research is specific to Sarapiquí county, the results can be applied to similar rural areas that are characterized by industrial agribusinesses.

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CHAPTER 1: FOOD INSECURITY ACROSS DIFFERENT SOCIAL-ECOLOGICAL ENVIRONMENTS AND ITS IMPACT ON DIET AND NUTRITION AMONG GIRLS IN RURAL COSTA RICA

Abstract

Food insecurity during childhood and adolescence can have long-term consequences on growth, development, and health. Rural communities in Costa Rica are particularly vulnerable to food insecurity, but spatial inequalities that exist *within* rural spaces are often overlooked within traditional approaches to rural poverty research. Here we explore the prevalence of food insecurity, the contributions of demographic and socioeconomic variables including social-ecological contexts (SEC) to food insecurity risk, and the impacts of food insecurity on diet, nutrition, and pubertal timing among a cross-sectional sample of 192 girls (8-18 years) in rural Costa Rica. Data were collected from a sociodemographic survey, the Food Insecurity Experience Scale (FIES), a 24-hour dietary recall, and anthropometry. Approximately 54% of participants were food insecure, with 15% experiencing moderate to severe food insecurity. Girls from households with incomes below the median were three times more likely to be food insecure compared to those with incomes at or above the median (OR = 3.14, p = 0.001). Participants from rural agricultural and urban/peri-urban environments were more vulnerable to food insecurity compared to those who lived in rural non-agricultural communities (OR = 3.94, p = 0.005; OR = 3.88, p = 0.007). Food insecurity was associated with less fat consumption (634 calories from fat vs. 744 calories, p = 0.017), lower BMI z-scores (0.04 vs. 0.06, p < 0.001), and lower odds of obesity (OR = 0.27, p = 0.053). Food insecurity was not, however, associated with the timing of pubertal landmarks including thelarche, pubarche, and menarche. The

findings highlight areas for policy intervention by indicating spatial inequalities related to food insecurity risk and the connections to diet and nutritional status within a rural understudied and underserved region of Costa Rica.

Introduction

Food insecurity is defined as inconsistent access to safe, nutritious, and preferred foods necessary for "normal growth and development and an active and healthy life" (FAO, n.d.-b). The definition used by the Costa Rica Ministry of Health incorporates limited availability, capacity, or uncertainty of obtaining nutritious and safe foods, capturing a wide range of relative factors and experiences associated with food insecurity (Ministerio de Salud, 2021b). Food insecurity is a growing issue in Costa Rica and is connected to increasing poverty rates, rising food prices, and climate change (Caravaca Rodríguez & Ugald Monteroe, 2020; Ministerio de Salud, 2021b). In 2022, the country documented an increase in poverty especially in rural zones (INEC, 2022), paired with a 22.3% increase in the prices of food (Jiménez Córdoba, 2023). Approximately 36% of households in Costa Rica face some level of food insecurity, with 16% of the population experiencing moderate to severe food insecurity (Caravaca Rodríguez and Ugalde Montero, 2020). Among households with children, 55% are food insecure (Pereira et al., 2021). Food insecurity also disproportionately impacts rural communities in Latin America and Costa Rica, which have lower mean household incomes compared to the national and urban averages and face non-economic barriers to food security such as distance to stores, community isolation, and fewer foods and ingredients available to choose from (Caravaca Rodríguez & Ugald Monteroe, 2020; INEC, 2022; Ministerio de Salud, 2021b; Rodríguez-González et al., 2020). The highest frequency of food insecurity in Costa Rica is found in the

Huetar Norte (22.7%) region, which is primarily rural and the most impoverished region (source: data from INEC, 2023 available at https://inec.cr/estadisticas-fuentes/encuestas/encuesta-nacional-hogares?filtertext=pobreza).

Food insecurity has been associated with poorer quality diets among adults and subadults including lower dietary diversity and malnutrition. In middle- and high-income contexts, food insecurity often contributes to diets higher in processed foods (Hutchinson & Tarasuk, 2022; Leung et al., 2022; Waxman et al., 2015). In lower-income areas, food insecurity may be more associated with staple food consumption and fallback foods (Araújo et al., 2018; Bernal et al., 2016; Monge-Rojas et al., 2021). In Costa Rica, (Comisión Intersectorial de Guías Alimentarias para Costa Rica, 2011) food-insecure adolescents have been found to consume more staple foods (for example, the traditional rice and legumes) compared to food-secure individuals(Monge-Rojas et al., 2021). Thus, depending on context food insecurity can contribute to overnutrition, undernutrition, or both creating a dual burden of malnutrition. For example, dependence on either ultra-processed items or starchy staples may reflect a diet high in calories but low in micronutrients. As a result, it is common to observe micronutrient deficiencies among food insecure individuals including those considered to be overweight or obese (Fao et al., 2019; Shimabuku et al., 2020; Tzioumis & Adair, 2014). On the other hand, moderate to severe food insecurity, resulting in calorie reduction and/or hunger, can cause undernutrition and stunting and wasting among children and adolescents (Alaimo et al., 2020; Moradi et al., 2019).

Malnutrition during adolescence has immediate and long-term consequences. Adolescence is a period of the life course characterized by accelerated musculoskeletal growth, sexual maturation, and brain development. Malnutrition during this critical period is associated with growth retardation, suboptimal cognitive development and abilities, and increased risks for infectious and chronic diseases including type-2 diabetes, cardiovascular diseases, asthma, and immune suppression (Gundersen & Seligman, 2017; Maldonado et al., 2022; Moradi et al., 2019; Thomas et al., 2019). Beyond malnutrition, food insecurity as an experience is associated with stress, mental health conditions, and lower quality of life among adolescents (Heflin et al., 2019; Thomas et al., 2019).

It is the impact of food insecurity on both nutritional status and stress that has led investigators to explore the connections between food insecurity and the timing of puberty among girls. Life history theory explains that metabolic energy can only be allocated to one organismal task (Said-Mohamed et al., 2018). Therefore, organisms constantly make energetic trade-offs, where energy may be used for one purpose, such as fighting an infectious disease or responding to a stressful event, and therefore cannot be used for others such as growth or reproduction. Reproductive maturation is energetically costly, especially since musculoskeletal growth and brain development continue throughout adolescence (Bogin, 1994; Reiches, 2019). Sufficient energetic resources are necessary to maintain healthy growth, development, and reproductive efforts such as the start and continuation of ovulation and subsequent menstruation. Undernutrition has therefore been connected to later pubertal development, as one may not have sufficient metabolic resources necessary for this costly developmental transition (Campisi et al., 2018). Overnutrition, on the other hand, is often associated with earlier puberty as energy stores signal sufficient resources to allow for earlier maturation and reproduction (Ellison, 2017; Villamor & Jansen, 2016). While psychosocial stress may be energetically costly, studies find an inverse association between stressful early life environments and pubertal timing. For example, harsh rearing environments during infancy and early childhood have predicted earlier age at menarche, the first menstrual cycle (Chisholm et al., 2016). Psychosocial stress can act as a cue for intrinsic mortality risk; in the context of high infant mortality or adult mortality risk, life history strategies may shift from long-term survival to investment in reproductive fitness (Chisholm et al., 2016).

Food insecurity provides a unique opportunity for understanding the determinants of menarche because it involves both nutritional stress and psychosocial stress, which vary by context. Life history theory assumes that when food insecurity is associated with undernutrition and/or exists concurrently with high juvenile mortality risk, available energy is allocated for somatic needs rather than for reproduction and menarche is delayed. In Sarapiquí, Costa Rica, there is substantial risk for infectious zoonotic diseases such as dengue and malaria. On the other hand, when food insecurity associates with overnutrition and low extrinsic mortality risk, it is expected that females will have enough energy to sustain somatic needs as well as reproductive maturation and may begin puberty earlier.

It is also useful to consider social-ecological contexts (SEC) when assessing the determinants and consequences of food insecurity. *Social* encompasses economic, political, technological, behavioral, and cultural factors, and, hence, is human-driven, while *ecology* comprises the natural environment, and these components interact with and influence one another (Bograd et al., 2019; Brondizio et al., 2016). The SEC framework allows for the evaluation of the causes and consequences of spatial inequalities, which refer to “how and why valued resources vary across places, and how places themselves become markers and makers of inequality”(Hooks et al., 2016). It is a useful lens to explore how various structures connected to geographic context create and reproduce inequalities among individuals, households, and communities. Furthermore, a focus on spatial inequalities provides a base for understanding disparities *within* a space, rather than solely across spaces, which has been the tradition in social science (Hooks et al., 2016). Research on rural inequalities, specifically, continues to be positioned within comparative urban versus rural models, especially in rural poverty research. As a result, there is a gap in our understanding of the differences and inequities that exist *within* rural communities and their causes and consequences.

Objectives

This paper presents data on the prevalence of food insecurity among a sample of girls (age 8 -18 years) from varying SECs in Sarapiquí County, a rural agricultural region located in the Huetar Norte region of Costa Rica. We explore the determinants of food insecurity considering demographic variables (age, household size and composition, and parental nationality), socioeconomic status (paternal education, maternal employment, and income), and variation in SEC (rural agricultural, rural nonagricultural, urban/peri-urban, and mosaic agriculture-forest). Finally, we present the associations between food insecurity and diet, nutritional status, and puberty among girls in the sample. Because Sarapiquí is highly impoverished, highly rural, and has with many communities that are isolated from the main markets, we predict that food insecurity in this context will associate with monotonous diets reliant on staple foods (e.g., rice and beans) and lower caloric consumption among girls who are food insecure compared to those who are food secure. We also expect that food insecurity prevalence will be highest in the rural agricultural communities where most employment consists of low-wage jobs associated with absentee-owned agribusinesses and most women are unemployed (Estrategia Integral de Prevención para la Seguridad Pública, 2019; Municipalidad de Sarapiquí, 2022). Lastly, we predict that mediated through the connection between food insecurity and less energy-dense diets, food insecurity will associate with later pubertal timing.

Materials and Methods

Description of Research Site

Sarapiquí county is situated in north central-northeastern Costa Rica. It is the largest county in the province of Heredia and makes up the eastern section of the larger Huetar Norte region. The northern border of Sarapiquí meets southern Nicaragua, and Nicaraguan immigrants account for a large portion of the population and physical labor force (INDER, 2015; INEC 2011, n.d.; Naranjo, 2014). The ecology is classified as tropical wet forest (i.e., rainforest) with some premontane wet forest in the lowlands. Deforested areas characterized by large-scale agricultural plantations are common in the lowlands (Jadin et al., 2016).

Sarapiquí is considered among the most rural counties in Costa Rica, and 89% of residents live in rural areas (Estrategia Integral de Prevención para la Seguridad Pública, 2019). Around 40% of the population in Sarapiquí have monthly incomes below the rural poverty threshold (monthly incomes less than ₡99,537 colones or $191.27 USD), as determined by The National Institute of Statistics and Censuses (Estrategia Integral de Prevención para la Seguridad Pública, 2019; INEC, 2022). Higher rates of poverty are found among rural households and Nicaraguan immigrants (Estrategia Integral de Prevención para la Seguridad Pública, 2019; INDER, 2015). Around 27% of households considered “rural” by government planning agencies are impoverished and nearly 10% face extreme poverty. In the small urban centers of Sarapiquí, approximately 17% of households live in poverty with around 5% experiencing extreme poverty (INDER, 2015). The county is among the least developed (INDER, 2015), and the province has the second-highest infant mortality rate in Costa Rica (INEC, 2022) (source: data from INEC, 2023 available at https://inec.cr/estadisticas-fuentes/encuestas/encuesta-nacional-hogares?filtertext=pobreza).

Many communities in Sarapiquí are isolated due to their rurality in what can be characterized as food deserts—places with little to no access to food, especially fresh and nutritious food, "due to the absence or low density of food entry points within a practical traveling distance" (FAO, 2017b). Ironically, food insecurity and food deserts are juxtaposed against a rich agricultural landscape. A large part of the county is distinguished by large-scale, monoculture landscapes, particularly banana and pineapple plantations (INDER, 2015; Jadin et al., 2016). Agriculture accounts for most of the county's economy and 66% of jobs(INDER, 2015). Most agribusinesses are owned and operated by foreign oligopolies that control a large share of the global food supply chain. The dominance of the monoculture industry, particularly banana and pineapple agribusinesses, is considered a factor contributing to the low level of economic development and sustained poverty in Sarapiquí.

Recruitment & Sampling Strategy

The study protocol was approved by the Indiana University Institutional Review Board, the Ethical Scientific Committee of the University of Costa Rica, and the National Health Research Council of the Ministry of Health of Costa Rica. All research was performed in accordance with the Declaration of Helsinki. Participants were first recruited in person at various schools and community organizations where researchers provided a brief overview of the study and consent/assent forms to students (and parents if present). Snowball recruiting was used in which participants were asked for names and contact information of eligible peers and/or family members. Girls had to be at least eight years of age and preferably under 17 years[1]. All participants provided written informed consent from a parent or guardian along with informed assent. Participants chose the date, time, and private location of the survey and interview, and most took place in the participant's home. Due to limited forested communities and low population sizes in non-agricultural rural areas, the final sample of 192 girls is slightly biased in favor of agricultural and urban/peri-urban spaces.

While a parent or guardian was typically present at the time of the surveys and interviews, all questions were directed at the girls. Most were able to answer questions without the help of an adult, aside from the questions on monthly income and parental education.

Sociodemographic Data

A survey was used to collect sociodemographic information including birthdate, nationality of girls and their caretakers, household size and composition, current and past residencies and their durations, monthly household income, caretakers' education and occupation(s), distance to the nearest agricultural plot and the commodity grown, and distance to the nearest forest. Birthdate was used to calculate the exact age at the time of the survey. Household size was categorized into those of 2 to 3, 4, 5, and 6-9 individuals, inclusive of participants. Nationality was coded for Nicaraguan vs. Costa Rican, and household composition was used to group the sample by single caretaker and multiple caretaker households. Because

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[1] Two exceptions were made when a participant had a sister older than 16 years who wanted to participate.

the distribution of income was heavily skewed to the left, median monthly household income was used to dichotomize the sample into households above or below the median household income (₡300,000).

Current residency, distance to agriculture, and distance to forest were used to categorize participants by SEC including rural agricultural, rural nonagricultural, urban/peri-urban, and mosaic agriculture-forest. Rural agricultural areas are characterized by monoculture landscapes and industrial agribusinesses. Rural nonagricultural environments do not encompass conventional or industrial agriculture and may or may not include forest. The urban/peri-urban environment refers to small urban centers and their nearby peri-urban neighborhoods within the rural region. These small centers link the rest of the region to goods and services including supermarkets, government offices, health clinics, and sometimes banks. Lastly, the mosaic agriculture-forest environment consists of rural landscapes that have both agriculture and forest and are not dominated by one or the other.

Food Insecurity

To assess food insecurity, we used the Food Insecurity Experience Scale (FIES) for Costa Rica from the Food and Agriculture Organization (FAO). The FIES was initially created by the FAO for a regional initiative in Latin America and the Caribbean in the early 2000s (Ballard et al., 2013). The scale has eight questions designed to measure worry associated with food access, the ability to access healthy and nutritious food, dietary diversity, consumption patterns, and hunger (Ballard et al., 2013; Cafiero et al., 2018). Participants (girls) who were comfortable reading and writing self-administered the survey. Girls who were not able to read and write efficiently answered the questions verbally.

Affirmative answers were coded as “1”, while negative answers were coded with “0” and summed to provide a raw food security score. The itemized responses were then validated and standardized in R Studio 4.3.0 using the Rasch model and the R package titled RM.weights. The FAO package weighs the scores based on global response and frequency data to provide the prevalence of moderate and severe food insecurity that are comparable cross-culturally (FAO, n.d.-a). The model does not classify individual participants or alter scores and was only used to obtain a weighted prevalence for the sample. For more information on the FIES and the Rasch model, see Cafiero et al 2018(Cafiero et al., 2018).

Raw total scores were used to assess individual food insecurity, with 1 or greater classified as food insecure (FAO, 2017a; Pereira et al., 2021). Food security status was dichotomized with 0 coding for food secure and 1 for food insecure. We did not use the raw score totals for further categorization or analyses per FAO recommendations. The dichotomous classification captured much of the variation in food insecurity, as 54% of the sample had a score of >=1 and was categorized as food insecure.

Diet

Dietary data were collected using 24-hour dietary recall. Girls were asked to list items consumed starting 24 hours prior to the time of the interview. They were prompted to describe all the ingredients in each dish, the quantities for each ingredient/food/beverage, brand names, flavorings, and the location and time of consumption. Utensils including plates, cups, bowls, and silverware were used to assist participants with quantity estimates.

Dietary recall data were entered into the University of Costa Rica’s 'ValorNut' program, an online program that calculates the nutritional value of foods (https://www.nutricion.ucr.ac.cr/index.php/es/valornut). ValorNut has predetermined food items based on the typical Costa Rican diet and products available in the country including commercial items and calculates calories, water, vitamins, and minerals.

Descriptions of foods and beverages, as categorized in ValorNut, were used to calculate the contributions of food groups to total calories. Ultra-processed (UP) foods were categorized using the NOVA food classification system which defines UP foods as ready-to-eat, drink, or heat “industrial formulations typically with five or more and usually many ingredients” and have ingredients “not commonly used in culinary preparations including additives whose purpose is to imitate sensory qualities of [unprocessed or minimally processed foods] or to disguise undesirable sensory qualities of the final product” with little to no whole foods or ingredients (Monteiro et al., 2019).

Total grams, calories, protein, carbohydrates, sugars (including natural and added sugars), fat, and fiber were calculated for each food/ingredient and summed for each participant.

Nutritional Status

Nutritional status was assessed using weight and height which were used to calculate body mass index (BMI). The World Health Organization (WHO) growth reference data for children and adolescents 5-19 years was used to calculate z-scores for height for age (HAZ) and BMI for age (BMIZ) (De Onis et al., 2007).

Puberty

Girls (often with the help of their maternal caretakers) were asked the age that they experienced three pubertal landmarks: thelarche, the initiation of breast development, pubarche, the initiation of pubic hair growth, and menarche, their first menstrual cycle. For menarche, we asked for a specific date. If girls or their maternal guardians did not know the date, we narrowed the occurrence down to the month and the year. The date was subtracted from their date of birth to provide an exact age at menarche.

Data Analysis

Exploratory analyses provided summary statistics for the sample and variables of interest. Univariate (unadjusted) logistic models tested the likelihood of food insecurity based on demographic (household size and composition), socio-economic (parental education, maternal employment, farm working caretaker, and income), and SEC categories. Covariates were tested for confounding, and those that were not significantly related were included in a multivariate (adjusted) logistic regression model. In regression models with categorical variables as predictor variables, the base comparison groups were chosen based on the median when the variable consisted of more than two groups (e.g., household size of 4 was used as the base comparison because the majority of the sample lived in households of 4). For non-dichotomous categorical variables, except for SECs, the base comparative group was that predicted to be less likely related to food *in*security (more likely connected to food security) based on the literature and ethnographic knowledge of the research context. For SECs, rural-nonagricultural SEC was chosen as the base comparison because a major research interest and hypothesis based on the literature is that communities not characterized by industrial agriculture are less vulnerable to food insecurity. To understand potential outcomes of food insecurity, T-tests were used to measure the differences in mean dietary variables (calories, protein, carbohydrates, total sugar, total fat, fiber, and food types), mean HAZ, BMIZ, and age at various pubertal landmarks (thelarche, pubarche, menarche) between the food-insecure and food-secure groups. Univariate logistic regression tested whether food insecurity predicted the risk of overweight, obesity, and menarche before age 12 years. Lastly, to see whether the determinants of food insecurity mediated any relationships between food insecurity and diet and nutritional status, all covariates were analyzed in univariate regression models and then in multivariate regression models with food insecurity when significance was determined. Statistical significance was established at $p<0.05$.

Results

Sample Description

Sample characteristics are found in Table 1. One hundred and ninety-two girls (192), ages eight to 18 years (mean = 12.9 years, SD = 2.48) participated in the study. All girls reported they were in school at the time of data collection. More than 95% of girls were born in Costa Rica, while 4% were born in Nicaragua. Household sizes ranged from two to nine people with an average household size of four. Around 32% of the girls' mothers and 29% of their fathers were immigrants from Nicaragua. Primary school was the most common level of educational attainment among both mothers and fathers. Around 42% of girls lived in a household in which at least one member worked as a farmworker or farmer. The median household income was ₡300,000 (approximately $450 per month at the time of data collection). Nearly 14% of girls lived in households with incomes below the poverty threshold(INEC, 2022).

Around one-third of girls lived in agricultural communities mostly characterized by plantations of banana ("*bananeras*") or pineapple ("*piñeras*") or in small urban centers or their surrounding peri-urban neighborhoods. The rest of the sample was dispersed in rural nonagricultural settings (either in forested settings or far from intensive agriculture) and mosaic landscapes of forest and agriculture.

Using raw score totals from the FIES questionnaire, 54% of participants experienced food insecurity within the last twelve months from the survey date. The FAO's Rasch modeling calibration method (Table 1) calculated that 15% of girls experienced moderate to severe food insecurity and 2% faced severe food insecurity. The most common affirmative responses were as follows: nearly 45% of respondents stated they had worried about not having enough food to eat during the last year, 25% reported only eating few foods due to lack of resources, and around 20% ate less than they thought they should due to resource restrictions. Ten percent stated they had gone hungry at some point, and 7% did not eat for an entire day due to limited resources.

Table 1. Sample Descriptives and Results of Unadjusted Logistic Regression Predicting Food Insecurity

Independent Variables	%	Food Insecure	Odds	95% Confidence
Household Size (2-9)				
2-3	28.4%	40.7%	0.81	0.37, 1.76
4	26.3	46.0%	--	--
5	24.7%	59.6%	1.73	0.77, 3.87
6+	20.5%	74.36%	3.40**	1.37, 8.45
Caretaker Nationality				
Costa Rican	57.3%	45.5%	--	--
Nicaraguan	41.7%	65.0%	2.23**	1.23, 4.03
Number of Caretakers				
Multiple	72.5%	35.8%	--	--
Single	27.5%	65.4%	1.92*	0.99, 3.72
Maternal Education				
None – Some Primary	18.4%	77.1%	2.85*	1.16, 7.01
Primary	44.2%	54.2%	--	--
Secondary	12.6%	37.5%	0.51	0.20, 1.29
University	9.0%	23.5%	0.26*	0.08, 0.86
Paternal Education				

None –Some Primary	24.7%	74.4%	3.51**	1.57, 7.85
Primary	48.3%	45.3%	--	--
Secondary	12.2%	50.0%	1.21	0.47, 3.08
University	5.6%	40.0%	0.80	0.21, 3.05
Maternal Employment				
Employed	52.6%	43.4%	--	--
Unemployed	47.4%	64.8%	2.40	1.34, 4.31
Farmwork				
Non-farming Caretaker	58.1%	49.1%	--	--
Farm working Caretaker	41.9%	59.5%	1.52	0.85, 2.73
Income				
≥ ₡300,000 ($450)	55.3%	43.8%	--	--
< ₡300,000 ($450)	44.7%	65.9%	2.48**	1.37, 4.47
SEC				
Rural Nonagricultural	17.9%	35.3%	--	--
Rural Agricultural	35.8%	65.2%	3.36**	1.42, 7.95
Urban-Peri Urban	33.7%	58.5%	2.68*	1.13, 6.35
Mosaic Agriculture-	12.6%	33.3%	0.92	0.30, 2.76

Showing results of univariate logistic regression models. Base variables include household size = 4, Costa Rican Nationality of caretaker, multiple-caretaker household, primary education, maternal employment, non-farm working household member, income at/above the median, and rural-nonagricultural environment. * $p =< 0.05$, ** $p < 0.01$, *** $p < 0.001$

The 24-hour dietary recalls showed that diets among the sample largely encompassed a mixture of traditional Costa Rican dishes and UP foods including sugary beverages. Table 2 provides a detailed summary of the dietary makeup and categorizations. On average, girls consumed 2,488 calories per 24-hour period. Carbohydrates made up the largest proportion of calories for the sample (61%), followed by fat (28%). Total sugar accounted for approximately 18% of calories consumed.

Table 2. Diet and Nutrient Intake from 24-hour Dietary Recalls

	Total Sample		Food Insecure		Food Secure	
Dietary Variables	**Mean[1]**	**% of Total**	**Mean**	**% Total**	**Mean**	**% Total**
Calories (kcal)	2487		2429		2549	
Protein (kcal)	302 (133)	12.4%	291 (119)	12.4%	314	12.3%
Carbohydrates (kcal)	1519	60.8%	1521	62.0%	1514	59.5%
Total Sugar (kcal)	446 (329)	17.9%	456 (356)	17.4%	455 (299)	18.2%

Total Fat (kcal)	687 (319)	27.6%	634	26.3%	744 (352)	29.0%
Fiber (g)	21 (12)	1.2%	20 (12)	1.1%	22 (12)	1.2%
Rice (kcal)	330 (176)	24.9%	338	29.4%	316 (171)	21.6%
Wheat (kcal)	188 (128)	4.5%	151 (78)	3.1%	211 (151)	5.1%
Legumes (kcal)	219 (161)	10.3%	210	10.5%	187 (165)	9.8%
Maíz[2] (kcal)	234 (239)	7.1%	250 (283)	7.0%	284 (238)	7.3%
Dairy[3] (kcal)	176 (149)	7.8%	170 (153)	7.7%	200 (174)	8.8%
Milk[4] (kcal)	225 (175)	6.0%	217 (172)	6.1%	237 (182)	6.1%
Fruit[5] (kcal)	123 (101)	8.1%	117 (97)	7.5%	133 (119)	9.6%
Vegetables[6] (kcal)	38 (64)	1.4%	43 (69)	1.4%	33 (53)	1.4%
Tubers (kcal)	167 (170)	1.8%	169 (191)	1.6%	165 (156)	2.2%
Typical Dishes[7] (kcal)	255 (203)	43.7%	254 (193)	47.3%	256 (176)	39.3%
Total UP Foods (kcal)[8]	234 (325)	42%	220 (245)	28.5%	228 (236)	33.4%
UP Snack Foods[9]	289 (231)	17.8%	283 (224)	12.1%	294 (226)	18.5%
Total Sweetened	166 (155)	10.2%	184 (181)	11.3%	146 (118)	9.6%
Commercial	148 (174)	6.0%	165 (208)	6.6%	129 (134)	5.4%

[1] The mean for food groups signifies the mean per item listed in the 24-hour dietary recalls for the total sample. The mean for nutrients is calculated from the total means of individual 24-hour dietary recall. Proportions for food groups stem from totals of the sample divided by total calories, while the proportions of nutrients were calculated by first calculating the proportion per individual and obtaining the mean proportion for the sample. [2] Maíz included corn eaten whole as well as items made primarily with corn such as corn chips and tortillas. [3] Dairy includes all items made from animal milk including liquid and powdered milk, cheese, yogurt, milkshakes/smoothies made with milk, ice cream, and coffee with milk. [4] The milk includes liquid and powdered milk and items made with liquid/powdered milk such as milkshakes/smoothies made with milk, ice cream, and coffee with milk where milk is a key ingredient but is not processed such as fermented or solidified. [5] Fruit includes solid fruit as well as fruit included in fruit juices (homemade or storebought). [6] Vegetables include those coded as vegetables in ValorNut, fresh or processed, but do not include tubers. [7] Typical dishes consist of *casados* (meat with rice, beans, and salad), mixed preparations with legumes, rice, or potatoes, and traditional street food including empanadas, sausage, chicharrónes, ceviche, picadillo, yuca, and plantain. [8] Ultra-processed (UP) foods include convenient foods, processed/sugary cereals, sandwich meat, processed cheese, white bread, hamburger/cheeseburger, hot dog, hamburger/hotdog buns, pancakes made with prepared-mix, French fries, salchipapas (French fries with hot dog or sausage link common in fast food/restaurants), pizza, canned and dehydrated soup mixes (e.g., ramen noodles, Sopa Maggie), canned ready to eat pasta (e.g., instant mac & cheese), condiments, sweetened beverages, and processed snack foods. [9] UP snack foods include chips, cookies, cakes, candy, ice cream and frozen treats, crackers; does not include sweetened beverages. [10] Total sweetened beverages include fruit juices made from fruits at home with added sugar & sweetened drinks made with milk along with the commercial items. [11] Commercial Sweeten beverages include instant mix drinks (e.g., tang), bottled/canned juices/beverages, and sodas) but do not include fruit juices made naturally from fruit or milk-based beverages made at home with minimally processed ingredients like rice or oats.

The largest portions of calories came from typical dishes (44%) and UP foods (42%). Around 35% of calories were from white rice, legumes, or dishes in which rice and/or beans were the main ingredients. Soup was also common but encompassed less typical homemade soups in comparison to UP commercial products such as dehydrated soup mixes (e.g., *Sopa*

Maggie, *Maruchan Ramen Noodles*). Approximately 18% of calories came from UP snacks and 10% from sweetened beverages (coffee with sugar was not included) with 6% coming from *commercial* sweetened beverages. Only 9% of calories were from fruits and vegetables, 6% from milk, and 2% from tubers.

Table 3 displays the mean and standard deviations for the anthropometric variables per age, and Table 4 presents z-scores and nutritional status indicators for the sample by age. The average HAZ for the total sample was -0.31. Only the age categories of 8-9 and 9-10 years had mean HAZ above zero. Based on HAZ, 5.7% of the total sample had stunted height (<-2 SD)(WHO, 2007). The age group with the highest frequency of stunting was 13-14 years.

The mean BMIZ for the total sample was 0.30. Around 26% (n = 50) of the sample had z-scores greater than 1 SD signifying overweight or obesity. More specifically, 20% had z-scores in the “overweight” category (1 SD >= 2 SD), 6.3% (n=12) were categorized as obese (> 2SD), and 3% (n = 6) had z-scores considered “thin” for their age. The age group with the highest prevalence of overweight z-scores was age 12, and age 11 had the highest rate of obesity.

A total of 163 girls had experienced thelarche, with an average of 10.9 years (SD = 1.6, range = 7-15 years). The mean age at pubarche for the 131 girls who had reached the milestone was 11.3 years (SD = 1.4, range = 6-15 years). Additionally, 126 girls had attained menarche by the time of data collection, and the average age at menarche was 11.8 years (SD = 1.1, range = 8-14.7 years). Around 87% of participants, often with the help of their maternal guardians, recalled the exact date or at minimum, the month and year of their first menstrual cycle. Their mothers reported an average age at menarche of 12.6 years.

Determinants of Food Insecurity

Table 1 presents the results from the univariate analyses of the determinants of food insecurity. Girls living in households with 6-9 individuals were three times more likely to be food insecure compared to those in four-person households (OR = 3.40, *p* = 0.008). Girls who lived with at least one caretaker of Nicaraguan nationality were two times more likely to experience food insecurity (OR = 2.23, *p* = 0.008) than participants whose caretakers were born in Costa Rica. Participants living in a single-caretaker household were also more likely to be food insecure (OR = 1.92, *p* = 0.054) when compared to girls living in households with multiple caretakers. Girls with maternal caretakers with no to some primary education were three times more likely to be food insecure compared to participants with maternal caretakers who had completed primary school (OR = 2.85, *p* = 0.022) and six times more likely than those with moms with secondary education (OR = 5.63, *p* = 0.003). Regarding paternal education, having no educational attainment was associated with greater food insecurity risk (OR = 3.51, *p* = 0.002) compared to having a primary education. Girls with maternal caretakers who were unemployed were also more likely to be food insecure compared to those with working maternal guardians (OR = 2.40, p = 0.003). Living in a household with a monthly income below the median associated with nearly three times higher likelihood of being food insecure compared to households with incomes at or above the median (OR = 2.48, p = 0.003).

Table 3. Mean (SD) Anthropometric Data by Age

Age (y)	n	Weight (kg)	Height (cm)	BMI
8	14	27.8 (3.8)	129.2 (4.6)	16.7 (2.0)
9	18	31.1 (6.9)	137.5 (7.3)	17.5 (2.8)
10	16	35.5 (9.0)	141.7 (8.9)	17.4 (2.9)
11	19	44.0 (11.6)	147.7 (5.3)	20.0 (4.5)
12	26	46.7 (8.7)	152.7 (4.5)	19.9 (3.2)

13	35	48.0 (9.3)	152.6 (6.9)	20.6 (3.5)
14	21	54.5 (11.6)	159.0 (8.6)	21.5 (4.0)
15	21	55.1 (10.8)	159.1 (7.9)	21.7 (3.3)
16+	21-22[1]	56.8 (10.0)	158.4 (3.7)	22.6 (4.1)

[1] One participant was removed from the weight, BMI, and triceps analyses due to pregnant status

Table 4. Z-scores and Indicators by Age

		Height for Age Z-scores					**BMI for Age Z-scores**				
Age (y)	**n**	**mean (SD)**	**≥-2 SD n (%)**	**-2 SD<-3 SD n (%)**	**<-3 SD n (%)**	**n**	**mean (SD)**	**<-2 SD n (%)**	**"normal"**	**"over-weight" 1 SD≥2 SD n (%)**	**obese >2 SD n (%)**
8	14	0.45 (1.60)	14 (100.0%)	0 (0.0%)	0 (0.0%)	14	0.35 (1.13)	0 (0.0%)	11 (78.6%)	1 (7.1%)	2 (14.3%)
9	18	0.26 (1.27)	18 (100.0%)	0 (0.0%)	0 (0.0%)	18	0.40 (1.10)	0 (0.0%)	13 (72.2%)	4 (22.2%)	1 (5.6%)
10	16	-0.02 (1.35)	14 (87.5%)	2 (12.5%)	0 (0.0%)	16	0.033 (1.29)	1 (6.3%)	13 (81.3%)	1 (6.3%)	1 (6.3%)
11	19	-0.03 (0.76)	19 (100.0%)	0 (0.0%)	0 (0.0%)	19	0.62 (1.30)	1 (5.3%)	12 (63.2%)	4 (21.1%)	3 (15.8%)
12	26	-0.27 (0.64)	25 (96.2%)	1 (3.8%)	0 (0.0%)	26	0.34 (1.09)	0 (0.0%)	17 (65.4%)	8 (30.8%)	1 (3.9%)
13	35	-0.82 (0.99)	30 (85.7%)	5 (14.3%)	0 (0.0%)	35	0.28 (1.08)	1 (2.9%)	25 (71.4%)	8 (22.9%)	1 (2.9%)
14	21	-0.29 (1.22)	21 (100.0%)	0 (0.0%)	0 (0.0%)	21	0.30 (1.18)	1 (4.8%)	14 (66.7%)	4 (19.1%)	1 (4.8%)
15	21	-0.46 (1.16)	19 (90.5%)	1 (4.8%)	1 (4.8%)	21	0.23 (1.02)	1 (4.8%)	16 (76.2%)	3 (14.3%)	1 (4.8%)
16+	22	-0.84 (0.86)	21 (95.5%)	0 (0.0%)	1 (4.6%)	21	0.13 (1.32)	1 (4.8%)	14 (66.7%)	5 (23.8%)	1 (4.8%)

*z-scores and cut-off categories determined using the WHO growth reference data for 5-19 years (2007)

The likelihood of being food insecure also varied by SEC. Girls living in rural agricultural communities were over three times more likely to be food insecure compared to the girls living in rural non-agricultural spaces (OR = 3.36, p = 0.006). Similarly, participants from urban and peri-urban environments were more likely to be food insecure (OR = 2.68, p = 0.025). The difference between mosaic and non-agricultural residency was not significant in terms of food insecurity risk.

The multivariate logistic regression model incorporated household size, caretaker nationality, income, and SEC as predictors of odds of food insecurity (see Table 5 for all outcomes). Although parental education was associated with food insecurity, it was not included in the logistic regression models as it was highly correlated with household size, parental nationality, and income. Similarly, the number of caretakers (single versus multiple) and maternal employment were strongly related to income and were not included in the multivariate regression analysis. In the multivariate model, income and SEC continued to predict the odds of food insecurity (Table 5). Having a monthly household income below the median predicted higher odds of food insecurity compared to households with incomes at or above the median (OR = 3.14, p = 0.001), and living in rural-agricultural (OR = 3.94, p = 0.005) and urban/peri-urban environments (OR = 3.88, p = 0.007) predicted greater odds of food insecurity compared to girls from rural nonagricultural communities.

Income was also associated with social-ecological environments. Living in an urban/peri-urban environment predicted a higher likelihood of monthly incomes equal to or greater than the median compared to rural non-agricultural environments (OR = 3.08, p = 0.011). However, both income and SEC were kept in the multivariate analysis as they were independently related to food insecurity.

Table 5. Results of Multivariate Logistic Regression Predicting Food Insecurity

Independent Variables	**Odds Ratio**	**95% Confidence Intervals**
Household Size		
2-3	0.79	0.34, 1.86
4	--	--
5	1.57	0.65, 3.76

6-9	2.38	0.91, 6.24
Caretaker with	1.78	0.93, 3.41
Income < median	3.14**	1.58, 6.24
SEC		
Rural Non-agricultural	--	--
Rural Agriculture	3.94**	1.51, 10.30
Urban/Peri Urban	3.88**	1.44, 10.39
Mosaic Agriculture-Forest	1.24	0.37, 4.11

Showing results of multivariate logistic regression. Base variables include household size = 4, Costa Rican Nationality of caretaker, multiple-caretaker households, income at/above the median, and rural-nonagricultural environment. * $p =< 0.05$, ** $p < 0.01$, *** $p < 0.001$

Associations between Food Insecurity, Diet, Nutritional Status, and Puberty

Typical foods accounted for a larger proportion of total calories among food-insecure girls compared to food-secure participants (47% vs 39%)(Table 2). On the other hand, the diets of food-secure participants included more UP foods, especially UP snack foods (33% vs 29%; 19% vs 12%, respectively). While food security status was not associated with calories, protein, carbohydrates, total sugar, or fiber, it was associated with fat consumption. On average, food-insecure girls consumed 634 calories from fat (26% of total calories), while food-secure girls consumed 744 calories from fat accounting for 29% of calories, on average ($t = 2.40$ $p = 0.017$).

Some of this variation stems from significant differences in sources of fat between the subsamples. Food insecure girls ate fewer calories from fat per serving, on average, from chicken (42 kcal vs 84 kcal, $p = 0.000$), ice cream (119 kcal vs 191 kcal, $p = 0.044$), cheese (76 kcal vs 122 kcal, $p = 0.039$), fast food, especially pizza, (119 kcal vs 221 kcal $p = 0.037$), and UP food (62 kcal vs 74 kcal, $p = 0.043$) compared to those who were food secure.

There was no significant difference in mean HAZ between food-insecure and food-secure girls (-0.43 vs -0.19, $t = 1.42$, $p = 0.155$). However, mean BMIZ did significantly vary between the groups, where food-insecure participants had an average BMIZ of 0.04 while food-secure girls had an average BMIZ of 0.60 ($t = 3.47$, $p < 0.001$). Similarly, more girls with BMIZ indicative of obesity (BMIZ ≥ 2.0) were food secure than food insecure (10% vs 3%) and food insecurity predicted lower odds of obesity in logistic regression (OR = 0.27, p = 0.053).

The only significant relationship between the independent variables and the diet/nutritional outcome variables was SEC and fat consumption. Living in a rural agricultural environment predicted lower fat consumption compared to living in a rural nonagricultural setting. However, when food insecurity was added as a covariate, the relationship became insignificant.

Food insecurity was not associated with age at thelarche, age at pubarche, age at menarche, or the likelihood of reaching menarche before age 12 years in the univariate analyses as well as in multivariate analyses exploring the role of fat consumption and BMIZ as a mediator between food insecurity and pubertal landmarks.

Discussion

In this sample of girls from Sarapiquí, we found that incomes below the median and urban/peri-urban and rural agricultural environments contributed to a greater risk of food insecurity after controlling for household size and composition. We also documented substantial consumption of UP foods and 26% of the sample had BMI z-scores indicative of overweight or obesity. However, food insecurity was negatively associated with both UP-food consumption and obesity. Food insecurity was not associated with the timing of pubertal landmarks.

The estimated prevalence of food insecurity as determined by the FAO FIES Rasch model for this sample is similar to FAO calculations for Costa Rica overall (16% of the population and 18% of adult females, face moderate to severe food insecurity)(FAO, 2018). However, national data do not differentiate ratios among children or households with children. A recent global analysis of food insecurity among households with children under the age of 15 documented that 55% of households in Central America and 40% of households in Costa Rica face some level of food insecurity related to limited economic resources (Pereira et al., 2021). Our food insecurity estimates are therefore comparable to Central America but higher than that of Costa Rica.

The higher prevalence of food insecurity in Sarapiquí is likely related to the rurality of the region and its strong ties to foreign-owned agricultural industries, both of which indicate low socioeconomic development, absence of alternative employment opportunities, and low wages especially for immigrant populations. Our sample had median and mean monthly incomes that were less than half of the national average for rural zones and one-quarter of that for urban areas (INEC, 2022). In addition, we found a high prevalence of single mothers, unemployment, and immigrants from Nicaragua, all of which are associated with lower incomes and consequently food insecurity (Caravaca Rodríguez & Ugald Monteroe, 2020; Ministerio de Salud, 2021b). Nationwide, food insecurity is more prevalent among immigrants, particularly those from Nicaragua (61% in 2022,(Moreno et al., 2022)).

Others have documented more vulnerability to food insecurity among rural households compared to urban areas in Costa Rica as well as Central America more (Hernández-Vásquez et al., 2022; Sibrian et al., 2021). In a study among families in the canton of Coto Brus, Costa Rica, which like Sarapiquí relies on agriculture and livestock as its main economy, investigators documented a food insecurity prevalence of 68% (Rodríguez-González et al., 2020). In the province of Guanacaste, researchers also found rural residency increased the risk of food insecurity compared to urban (Cerdas-Ramírez & Espinoza-Sánchez, 2018). Beyond relatively lower incomes, rural communities in Costa Rica face additional challenges. Most rural communities do not have supermarkets and individuals must travel to buy food, which induces substantial transportation costs. Furthermore, some may not have access to tap water or electricity and must buy water and gas to cook with, incurring additional expenditures.

As expected, income was a strong predictor of food insecurity in our sample. Economic resources are necessary for food security among most households that depend on commercial foods. In a study assessing determinants of resilience to food insecurity in Central America and the Caribbean, researchers found that income or salary was the strongest protector against food insecurity in Costa Rica(Rodríguez-González et al., 2020). In our sample, income was also a mediating factor within the connections between food insecurity risk and single-mother households, lower parental education, and maternal unemployment. Thus, these are areas in which policy interventions could be invaluable in improving income and subsequently food security in Sarapiquí. Specifically, more employment opportunities for women, particularly single mothers, and the assurance of equal pay between males and females is vital, especially since education level was not associated with the employment status of maternal caretakers. Because increasing employment opportunities requires development and investment in Sarapiquí, more immediate support is necessary for single-caretaker households to mitigate food insecurity among households with children.

We found inequalities existed at the sub-county level, between social-ecological spaces but within the politically- and culturally recognized setting of Sarapiquí. While food insecurity was highest in rural agricultural communities in our sample, it was also common among girls from small urban centers and peri-urban communities. This is likely because while the constructed spaces and what they offer may differentiate the “urban” and “rural” communities in Sarapiquí, the people and their lived experiences, including challenges, are not distinct from one another. In our sample, there were no significant differences in income, household size, and household composition across the various SECs. Both the urban and rural agricultural communities had an equal proportion of Nicaraguan caretakers and similar proportions of single mothers and households in poverty, all possible contributors to food insecurity.

The greatest variation in food insecurity prevalence and severity was not between the rural and small urban centers. Rather, the strongest contrasts were found within rural spaces—between rural communities characterized by industrial agriculture and rural communities without agriculture. The spatial inequalities framework posits that inequalities at the sub-national, sub-territorial, and, in the case of our sample, sub-county level stem from differences in economic structures (e.g., industrial activities, development, and the distribution of economic growth and resources), institutional arrangements (e.g., education, training and employment opportunities, social services), geographical location, the political importance of the space(s), and the history of economic, institutional, and spatial factors within the spaces (Hooks et al., 2016). In Sarapiquí, the rural agricultural communities are home to foreign-owned agribusiness. These SECs also had the lowest mean incomes, the highest frequency of food insecurity, and relatedly, lower fat consumption. These findings complement the expansive literature documenting the risks and negative impacts of the presence and activities of agribusiness on nearby communities. A comprehensive review of 51 articles finds communities with industrialized agriculture have relatively lower incomes, more poverty, more income inequality, and higher unemployment rates (Hooks et al., 2016; Lobao & Stofferahn, 2008). In addition, agribusinesses have increasing control within local political decision-making leading to a lack of governance around resource depletion, land grabbing, workers' rights violations including unfair wages, and pollution of local natural environments (Lobao and Stofferahn, 2008). In relation to food insecurity specifically, a study in Costa Rica found that food-secure families were more likely to have forest on their properties than food-insecurity households in rural areas of Costa Rica, indirectly relating land use and food (in)security.

Governance of agribusiness is key to improving the lives and wellbeing of rural communities. Policies should ensure agribusinesses provide fair wages, especially among immigrant workers who made up half of the farm-working caretakers in our sample. Ensuring a living wage for farmworkers will help to mitigate food insecurity by improving economic access to transportation, water, and food.

Consequences of Food Insecurity Among This Sample

Food insecurity was associated with slightly less fat and UP food consumption, lower BMIZ, and lower odds of obesity among girls in the sample. In the whole sample UP foods made up nearly half of the calories consumed while whole food and fiber consumption was minimal. Food-insecure girls consumed more traditional foods while the diets of food-secure girls comprised more UP foods and fat from UP foods. Lower fat consumption was found among girls in rural agricultural environments, but this relationship was mediated by food insecurity. Our findings are comparable to those of a recent study of diet among adolescents from rural and urban communities in central Costa Rica that showed higher consumption of traditional foods among adolescents from lower socioeconomic backgrounds and rural areas, and higher rates of obesity among adolescents from households with higher socioeconomic status (Monge-Rojas et al., 2021, 2024). Higher fat intake is commonly associated with higher incomes in Latin America (Fao et al., 2019) and lower fat consumption has been a documented effect of food insecurity among Hispanic/Latinx youth in the U.S. (Maldonado et al., 2022). In addition, a study in Brazil found more traditional food consumption, specifically beans, among food-insecure individuals compared to their food-secure counterparts (Araújo et al., 2018).

The relationship between food insecurity and lower BMIZ and obesity risk among children is compatible with some findings within Latin America and Costa Rica (Isanaka et al., 2007; Pertuz Guzmán, 2016; Ruderman & Mora, 2022). In a recent study among households from another rural farming area of Costa Rica, researchers found higher frequencies of overweight and obesity among the food and nutrition-secure families (Rodríguez-González et al., 2020). The prevalence of overweight and obesity among food-secure and higher-income households may be related to the consumption of fried, high-fat, and UP foods paired with the low consumption of whole foods including fruits, vegetables, and whole grains among our sample as well as others in Costa Rica. However, diet and BMI were not significantly related, and BMIZ was not associated with any of the covariates related to food insecurity in this sample, including fat consumption, income, and SEC. Therefore, we cannot explain the connection between food insecurity and BMIZ further and encourage more research. There may be other underlying factors not included in this analysis such as exposure to synthetic organic chemicals (e.g., pesticides, PBDEs) known to cause endocrine disruption and interfere with metabolic processes, especially since individuals in rural agricultural communities have higher rates of food insecurity compared to nonagricultural areas. We will assess this potential relationship in forthcoming analyses.

Notably, 20% of the sample had BMI z-scores indicative of being overweight, and 6.3% obese. These percentages are higher than those reported among children ages 5 through 13 in the county (7.9% overweight and 4.2% obese (Ministerio de Salud, 2021a)). However, it is lower than the national level of 31.7% (overweight) of children and adolescents ages five to 19 years (González Rivera et al., 2023). The difference is likely reflected in the differences in age distributions in the samples as well as the rurality and prevalence of food insecurity in our sample. National and regional studies have shown lower overweight and obesity rates among more rural provinces (González Rivera et al., 2023).

The lack of associations between food insecurity and puberty is likely the result of a lack of significant variation in diet, nutritional status, and stress between food insecure and food secure girls. While there was a difference in fat consumption, BMI, and obesity rate, food insecurity generally was not predictive of over- or undernutrition. Furthermore, there may be other environmental factors that have a stronger influence on the timing of puberty among this sample such as exposure to endocrine-disrupting pesticides associated with nearby industrial agriculture operations.

Limitations

Food insecurity as a dichotomous variable may not capture enough variation in lived experiences among rural low-income samples and is a limitation in using the FIES. The sample was strikingly uniform with regard to socioeconomic, demographic, and nutritional factors, limiting statistical analyses. Dietary behaviors were highly similar across participants, not associated with income, and only fat consumption varied between the food secure and food insecure groups and the difference in calories was minimal. We do not feel the lack of variation is due to the sampling strategy, as we sampled as broadly as possible. However, further research using a larger and more representative sample is recommended.

We also note although there are structural differences between the small urban centers and the rest of the rural county, Sarapiquí as a whole is rural. Thus, the traditional categorization and comparative approach using “urban” versus “rural” in Sarapiquí, as well as other rural areas of Costa Rica, is likely not an effective strategy for capturing variability (Samper & González, 2020). As our model highlighted, most of the variability was found *within* the “rural” settings and not between rural and urban communities.

Another limitation is the use of BMI among children and adolescents, particularly those experiencing pubertal maturation. BMI does not account for different mass types such as muscle versus fat, and therefore has been critiqued as a measure of body fat. This critique is even more relevant for youth who are in the process of maturation, including metabolic and hormonal changes. Thus, the findings related to BMI in this sample should be considered cautiously. Furthermore, HAZ did not vary significantly across the sample, which may point toward a lack of overall variation in this population or limitations of using traditional anthropometric measures and references during pubertal development which may serve as a period of catchup growth (Belachew et al., 2013; Prentice et al., 2013).

Conclusion

This paper presents valuable data on food insecurity prevalence, diet, and nutrition among girls from the understudied rural county of Sarapiquí. We document a high prevalence of child/adolescent food insecurity paired with overall low household incomes, considerable consumption of UP foods, and that over one-quarter of girls were overweight and obese. Additionally, spatial inequalities related to food insecurity and income were present. Girls in rural agricultural and urban/peri-urban communities and those from households with incomes below the median were most vulnerable to food insecurity. Food-insecure girls consumed fewer calories from fat and had lower BMIZ compared to their food-secure counterparts. Unlike trends documented among samples from middle- and high-income countries, food insecurity in this context was not associated with overweight or obesity; nor was it associated with frank malnutrition indicators.

Compared to the frequency of food insecurity for the region of Huetar Norte and the country of Costa Rica, girls in Sarapiquí, and their households by extension, disproportionately experience food insecurity. We expect that rurality and the presence of foreign-owned industrial agribusinesses play a role in the pervasiveness of food insecurity in this sample. Therefore, we provide further evidence of the downstream impacts of industrial agriculture on nearby communities, related negative impacts of industrial agriculture on nearby communities, and, in the case of our sample, children and adolescents. The findings highlight spatial inequalities within rural Costa Rica and the need for political interventions including the enactment of living wages particularly among agricultural employees, increasing investments and developmental efforts to fuel socioeconomic improvements, equal employment opportunities, and access to markets, and immediate support for single-caretaker and low-income households through the provision of supplementary income and/or food.

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CHAPTER 2: THE DETERMINANTS OF PESTICIDE EXPOSURE AMONG GIRLS IN SARAPIQUÍ, COSTA RICA

Abstract

Pesticide exposure during childhood and adolescence can disrupt endocrine- and metabolic functions which may increase the risk for chronic diseases including cancer. Thus, it is important to understand the determinants of pesticide exposure among youth, especially in rural agricultural areas where individuals are more likely to be exposed due to the application of pesticides in nearby fields. This analysis explores the contributions of social-ecological context (SECs: rural agricultural, rural nonagricultural, urban/peri-urban, and mosaic), household factors (composition, occupation of household members, and income), perceptions of personal pesticide exposure, and distance to agricultural fields (general, pineapple, and banana) and forest to exposure to current-use pesticides (CUPs) and organochlorine pesticides (OCPs) and metabolites among a sample of girls from Sarapiquí, Costa Rica. Information regarding SECs, household factors, and perception of pesticide exposure was collected using household surveys (n=192). Exposure concentrations of CUPs and OCPs were measured on a subsample (n = 54) using silicone wristbands which were worn by girls for an average of 4.5 days and analyzed using liquid/gas chromatography and mass spectrometry. We found higher mean levels of log-transformed CUPs and OCPs among the rural agricultural samples compared to urban/peri-urban samples, and higher levels of log-transformed ametryn and diazinon, in agricultural samples compared to rural non-agricultural samples. Distance to any large-scale monoculture fields and pineapple plantations, specifically, was negatively correlated with concentrations for CUPs, ametryn, and diazinon. OCPs were significantly related to SECs, where

living in an urban community predicted lower levels of OCPs compared to girls from rural agricultural communities.

We provide the first data on personal pesticide exposure among children and adolescents from an understudied and vulnerable population of Costa Rica. Furthermore, this is the first investigation to use silicone wristbands to measure individual passive chemical exposure in Costa Rica (to our knowledge). We show exposure to current-use- and legacy organochlorine pesticides is widespread and not dependent on household factors. Living closer to pineapple agriculture was associated with higher exposure to current-use pesticides, suggesting that pesticides applied to pineapple fields are not contained within the plantations, and community members are vulnerable. Pineapple agriculture continues to rapidly expand in Sarapiquí and across Costa Rica. Therefore, community members, especially children, and natural resources (e.g., water sources, forests) must be protected from the intensive use of hazardous agrochemicals by pineapple agribusinesses.

Introduction

Comparing globally, Costa Rica applies some of the highest quantities of pesticides per hectare of agricultural land (Vargas Castro, 2022). The country is the global leader in fresh pineapple exportation, accounting for 85% of the U.S. pineapple market (Vargas Céspedes et al., 2017), and Costa Rica ranks first for the quantity of bananas-per-hectare produced (Vargas Céspedes et al., 2017). Such intensive agriculture is accompanied by a reliance on agrochemicals, especially pesticides. Costa Rica's banana agribusiness uses the highest quantities of pesticides, with more than 1.5 million recorded kgs applied in 2020 alone (Vargas Castro, 2021). Following banana is grass grown for cow feed and pineapple operations, with around 1 million kg of pesticides applied annually to pineapple fields (Vargas Castro, 2021). The primary pesticides used for banana cultivation in Costa Rica include the insecticides ethoprophos, fenamiphos, cadusafos, chlorpyrifos, and bifenthrin, and the fungicides mancozeb, tridemorph, fenbuconazole, tebuconazole, azoxystrobin, and trifloxystrobin (Alvarado-Prado et al., 2022; Costa Rica Ministry of Health, 2021). The most used pesticides for pineapple agriculture include the herbicides ametryn, bromacil, diuron, and paraquat, the insecticides diazinon, ethoprophos, and carbaryl, and the fungicides tridim, mancozeb, metalaxyl, triadimefon (Alvarado-Prado et al., 2022; Costa Rica Ministry of Health, 2021). Many of these pesticides are banned in other countries and the European Union because they pose health risks. These include ethoprophos (37 bans), fenamiphos (35 bans), cadusafos (37 bans), chlorpyrifos (39 bans), bifenthrin (30 bans), mancozeb (31 bans), tridemorph (33 bans), tebuconazole (1 ban), ametryn (30 bans), bromacil (33 bans), diuron (31 bans), and paraquat (58 bans), diazinon (39 bans), carbaryl (41 bans), metalaxyl (1 ban), and triadimefon (31 bans) (PAN, 2022).

Sarapiquí is a rural agricultural region located in Costa Rica's Huetar Norte zone. It is home to Costa Rica's second banana expansion, which began in the 1960s (Guillén Araya, 2018). More recently, Sarapiquí has also become a primary site for pineapple monoculture (León Sáenz & Arroyo Blanco, 2018; Vargas Céspedes et al., 2017). Accordingly, agricultural operations account for most of Sarapiquí's economy and over 50% of local employment (Municipalidad de Sarapiquí, 2022).

Pesticide exposure is part of the broader exposome, an individual's total environmental exposure load throughout the life course (i.e., accumulative life exposure load) (Goodrich et al., 2016; Vrijheid, 2014; Wild, 2012). There is evidence that pesticide exposure during the critical developmental periods of childhood and adolescence is particularly problematic and associated with risk for both acute and chronic diseases (Mallozzi et al., 2016; Sarkar et al., 2021). These include impacts on sexual maturation and reproductive health as many pesticides are known to have endocrine-disrupting effects (Gore et al., 2015; Marcu et al., 2023). For example, some investigations show that exposure to the OCPs DDT and HCB as well as the classes of organophosphate and pyrethroid pesticides (analyzed by testing for broad-spectrum metabolites such as diethylthiophosphate and dimethyl phosphate) during adolescence is associated with later sexual maturation and menarche, specifically, while prenatal exposure to a pesticides, in general (e.g., mothers who worked in greenhouses during pregnancy), has been connected to earlier pubertal development (Attfield et al., 2019; Bapayeva et al., 2016; Castiello et al., 2023; Castiello & Freire, 2021; Uldbjerg et al., 2022; Wohlfahrt-Veje et al., 2012, 2016). The timing and rate of reproductive development are associated with health outcomes. Most notably, early pubertal development has been associated with increased risks for various chronic diseases including cancer and neurobehavioral disorders (Golub et al., 2008; Werneck et al., 2018; Yoo, 2016).

Given the potential impacts of pesticide exposure on reproductive development and long-term health, it is vital to understand the determinants of exposure among children and adolescents. Children and adolescents living in rural agricultural communities or with farm-working household members are vulnerable to pesticide exposure from environmental contamination by pesticides applied to crops and secondary exposure (Alvarado-Prado et al., 2022; Sarkar et al., 2021). In this assessment, we explore variation in exposure to current-use pesticides (CUPs) and organochlorine pesticides (OCPs), also known as legacy pesticides, using silicone wristbands worn by a sample of girls from Sarapiquí, Costa Rica. OCPs, such as DDT and chlordane, were among the first industrially-produced pesticides and widely utilized across the world from the 1940s until the early 2000s(Bertomeu-Sánchez, 2019). Because OCPs are highly toxic, accumulate in human and animals tissue, and are highly persistent in the environment, they are included among the 29 persistent organic pollutants banned by the Stockholm Convention in 2004 (Stockholm Convention, n.d.). Costa Rica prohibited the use of the OCPs included in the Stockholm Convention treaty for agriculture in 1999 (Ministerio de Agricultura y Ganaderia de Costa Rica, 2024). However, the newer OCP endosulfan was not phased out in Costa Rica until 2016 (Rojas, 2016)Current-use pesticides (CUPs) are synthetic organic chemicals that were created to replace OCPs (Sánchez-Bayo, 2019). They continue to be altered and new ones created in response to target resistance or investigations of their environmental persistence and/or health impacts which has led to the phasing out of many (e.g., chlorpyrifos) (Sánchez-Bayo, 2019).

We compared exposure to CUPs and legacy OCPs across four different social-ecological contexts (SECs): rural agricultural, rural nonagricultural (forest, pasture, or both), urban/peri-urban, and mosaic (non-agriculture mixed with smaller-scale agriculture); and we tested for associations between pesticide exposure and household factors (household size and composition, income, employment in agriculture), perceptions of exposure, proximity to any large-scale monoculture field, pineapple fields, and banana fields, and proximity to forest. Due to its mixed landscape of agriculture and forest, including the Braulio Carillo National Park, Sarapiquí provides an ideal setting to compare exposures across different landscapes. To our knowledge, only a few studies have measured pesticides in the environment in Sarapiquí, and most data were collected in the early 2000s (UNA & IRET, n.d.-b; Wang et al., 2019). This is the first study to measure *personal exposure* to pesticides in Sarapiquí; and the first investigation to use silicone wristbands to capture passive exposure among humans in Costa Rica. We predict that rural agricultural communities and living closer to monocrop fields will correlate with higher exposure concentrations for both OCPs and CUPs due to their proximity to application sites and atmospheric drift, and that girls living in rural nonagricultural settings which are far from industrial agricultural fields and/or encompass forest and/or pasture will have lower levels of pesticide exposure. We also predict that having at least one household member working in industrial agriculture will associate with higher exposure concentrations among the sample due to occupational exposure and drift on clothing and bodies.

Methods

The data presented in this paper are part of a broader study aimed at assessing the relationship between pesticide exposure, and reproductive maturation among girls from different SECs[2]. In this paper, we focus on one aspect, presenting novel data on pesticide exposure among a subsample of girls from the study.

Recruitment for the study utilized local schools, community organizations, and word-of-mouth. Researchers provided a brief overview of the study and consent/assent forms to girls and parents if present. Snowball recruiting was also used; participants were asked to recommend additional eligible girls. Since the study was designed to assess pesticide exposure

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[2] The findings on the relationships between SECs, pesticides, and reproductive development will be presented in a forthcoming paper.

and reproductive maturation, girls had to be at least eight years of age and preferably under 17 years. All participants provided informed consent from a parent or guardian along with informed assent. We aimed to sample evenly across the SECs, but the final sample encompassed more participants from agricultural areas due to the dominance of agriculture in the county, low population density in rural areas, and limited forested residential areas.

A survey was used to collect demographic and household information including birthdate, nationality of girls and their caretakers, household size and composition, monthly household income, household members' occupation(s) including type of work and workplace, and how long the girls had lived in their current location. The latter was used to calculate the number of household members working in agriculture and specifically in pineapple and banana production. Nationality was coded as Nicaraguan or Costa Rican, and household composition was divided into single-caretaker and multi-caretaker households. Because the distribution of income was heavily skewed to the left, median monthly household income was used to dichotomize the sample into households above or below the median household income (₡300,000, which translated to USD $450 at the time of data collection (March-June 2022)).

The survey also included questions about whether the nearest agricultural fields applied pesticides and whether participants worried about pesticide exposure to gauge perceived pesticide exposure and danger. Information regarding location and the commodities grown on the nearest agricultural plantations was also obtained during the survey and confirmed visually by field researchers. Distance to the nearest agricultural plot and distance to forest from each participant's home was calculated using Google Earth to create the variables "distance to any large-scale monoculture" and "distance to forest". Distance to any large-scale monoculture captured any type of agricultural commodity grown as while the largest industries are pineapple and banana, Sarapiquí is also home to various other commodity crop agriculture including ornamental plants, yuca, grass grown for cow feed, and palm grown for palm hearts, among others.

Current residency and distances to agriculture and forest were used to categorize participants by SEC[3] including rural agricultural, rural nonagricultural (forest, pasture, or both), urban/peri-urban, and mosaic (agriculture + forest). We also divided rural agricultural samples into two categories based on their proximity to banana[4] or pineapple plantations to assess whether pesticide exposure varied by whether someone lived in an area characterized by pineapple versus banana agriculture.

Silicone Wristbands

Silicone wristbands are a novel and noninvasive method of measuring passive exposure to environmental organic chemicals. Silicone sequesters organic compounds including volatile and hydrophilic chemicals (O'Connell et al., 2014). As a passive sampler, silicone wristbands worn by participants for a minimum of three days can be used to sequester and later measure organic contaminants that individuals are exposed to through air or water (O'Connell et al., 2014). They have been validated as a credible inference of estimated respiratory and dermal exposure, but not necessarily for exposure through ingestion although investigations find positive correlations (Samon et al., 2022; Venier et al., 2018). Because the method is non-

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[3] Rural nonagricultural environments do not encompass conventional or industrial agriculture. Their landscape is primarily forest or pasture or a mixture of forest and pasture. Urban/peri-urban environments refer to small urban centers and their nearby peri-urban neighborhoods within the rural region. Lastly, the mosaic environments consist of rural landscapes that have both agriculture and forest and are not dominated by one or the other.

[4] For this assessment, "banana agriculture" encompasses all banana varieties including plantains that are commercially grown in Sarapiquí.

invasive and has a low participant burden, it is a valuable and culturally appropriate option for non-Western samples and vulnerable groups such as children and pregnant individuals. Black silicone wristbands were purchased from 24hourswristbands.com (Houston, TX) and deployed to capture exposure to CUPs and OCPs. Before deployment, the wristbands were cleaned and individually wrapped in aluminum foil in the Venier Environmental Chemistry Laboratory at Indiana University. For a complete description of the protocols for silicone wristbands, see Wang et al., 2020 and Romanak et al., 2019. We used rivets to adjust the wristbands into smaller sizes to ensure a secure fit. At the initial household meeting, participants were given a pre-cleaned silicone wristband and instructed to wear it consistently for at least three days including while bathing, sleeping, and washing hands. At the collection meeting, the participants removed the wristbands and placed them in the original aluminum foil wrapping. The foil-wrapped wristbands were then placed in individual plastic bags, labeled, and immediately transported and stored in –20 C freezers until extraction.

Laboratory procedures took place in the Venier Environmental Chemistry Lab at Indiana University. We extracted and analyzed a subsample of 54 wristbands from the SECs according to the protocol published by Essandoh et al. (n.d.). The subsampled wristbands were stratified based on SEC, age, and household to ensure all SECs were represented, a wide age range, and samples were not from the same household. We additionally analyzed six field blanks which were used as controls for quality analyses and corrections (see Essandoh et al., n.d. for the full protocol). Blanks were subtracted from wristbands samples on a mass basis. We tested for 42 CUPs and 16 CUP metabolites and 15 OCPs and 6 OCP metabolites. The mass of chemicals on the wristbands were converted to concentrations (ng/g) using the wristband sample weights.

Data Analysis

Data analysis was conducted using Stata/SE 17. The power of the sample size was tested and confirmed the power of 98.3% for a sample size of 54 and a multiple linear regression with three covariates and an R^2 of 0.3. Sample and pesticide summary statistics were calculated. Because of the small sample size and stratification by SECs, which condenses the sample relative to the SEC grouping, we report detection frequencies (DFs) and concentrations of pesticides and their metabolites that were detected in 25% or more of the wristbands. The log for each pesticide variable was calculated and used for all hypothesis testing to achieve normality of the distribution. Univariate analyses tested for significant associations between log-transformed pesticide concentrations[5] (for CUPs, OCPs, and individual pesticides detected at 100% frequency) and SECs, household factors, perceptions, and distance to agriculture and forest, and included t-tests and linear regression. We additionally checked for relationships between covariates that were significantly related to pesticide exposure in the univariate models.

The study protocol was approved by the Indiana University Institutional Review Board, the Ethical Scientific Committee of the University of Costa Rica, and the National Health Research Council of the Ministry of Health of Costa Rica.

Results

Table 1 contains summary descriptions of the sample characteristics and detected concentrations for CUPs and OCPs. The mean age of the participants was 12.6 years, and most

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[5] Initially, we also tested associations with total pesticide load (sum of all CUPs and OCPs). However, all significant associations were driven by CUPs (but not OCPs). Thus, we felt it important to understand the determinants and variation in CUP exposure, specifically, while also assessing OCPs.

were born in Costa Rica. Girls wore the wristbands for an average of 108 hours, or 4.5 days (sd = 22.3). Around 44% lived with at least one household member who worked for a banana or pineapple agribusiness (primarily as field workers but occupations also included processing/packing, field supervisors, agrochemical warehouse employees, drivers, and cooks). More than 80% of participants stated that the nearest agricultural plantation applied pesticides, and reported that they could smell the chemicals and/or visually see them being applied (e.g., by plane, individuals, or tractors), felt droplets of pesticides on their skin, experienced physiological responses such as burning/watering eyes, skin rash, scratchy throat, and runny nose, and/or knew people who work on the farms who have confirmed pesticide utilization. Nearly 70% said they worried about pesticide exposure, with health consequences being the most common reason followed by negative environmental impacts.

Table 1. Sample Descriptives and Mean Pesticide Concentrations (CUPs: n = 54; OCPs = 52)

		CUPs	**OCPs**
Independent Variables	**%**	**Mean (SD)**	**Mean (SD)**
Household Size (2-7)			
2-3	27.8%	87.7 (148.7)	33.2 (41.2)
4	29.6%	138.6 (170.1)	22.7 (26.7)
5	24.1%	89.5 (56.9)	24.5 (50.3)
6-7	18.5%	220.8 (303.5)	21.3 (31.4)
Nationality			
Costa Rican	90.7%	130.1 (189.4)	161.2 (201.4)
Nicaraguan	7.4%	83.9 (51.6)	92.6 (55.5)
Other	1.9%	194.1 (n/a)	228.3 (n/a)
Caretaker Nationality			
+Costa Rican	63.0%	114.3 (161.7)	34.1 (45.0)
Nicaraguan	37.0%	151.0 (213.2)	11.2 (7.4)**
Number of Caretakers			
+Multiple	69.8%	151.0 (213.2)	24.4 (31.2)
Single	30.2%	73.7 (51.7)*	28.3 (50.9)
Farmwork			
+Non-farm Working Member	51.9%	105.7 (120.3)	25.4 (39.5)
Farm Working Member	48.2%	155.6 (236.9)	26.1 (35.8)
Income			

+≥ ₡300,000 ($450)	57.4%	152.4 (183.6)	20.3 (24.9)
< ₡300,000 ($450)	42.6%	109.7 (180.5)	32.5 (49.1)
Social-Ecological Context			
+Rural Agricultural	44.4%	200.5 (240.1)	36.1 (49.0)
Rural Nonagricultural	20.4%	84.3 (127.4)*	29.2 (36.3)
Urban-Peri Urban	25.9%	69.6 (37.5)	8.1 (3.6)*
Mosaic Agriculture-Forest	9.3%	38.5 (20.7)*	21.9 (19.2)
Residency			
Entire life	57.4%	162.1 (229.8)	26.2 (31.4)
Had lived elsewhere	42.6%	102.4 (133.4)	25.0 (42.4)
Apply Pesticides Nearby			
+Yes	81.5%	141.5 (197.0)	27.9 (41.3)
No	1.9%	98.2 (n/a)	24.0 (n/a)
Unsure	16.7%	64.3 (59.4)*	15.8 (11.2)
Worry about Pesticide Exposure			
+Yes	68.5%	98.9 (127.7)	20.6 (35.4)
No	27.8%	152.3 (186.5)	39.6 (42.4)
Unsure	3.7%	480.7 (616.3)**	10.7 (8.3)

Alpha <0.05, *p <0.05, **p<0.01, ***p<0.001;
CUPs = current-use pesticides, OCPs = organochlorine pesticides
+Base comparison variables: Household size of 4, Costa Rican nationality of sample and caretakers, multiple caretakers, non-farm working household member, income < ₡300,000, rural agricultural SEC, have lived elsewhere, and "yes" for pesticide application and worry

Table 2 lists the pesticides that were detected in at least 25% of the wristbands along with the detection frequencies[6] (DFs) and the mean concentrations detected for CUPs (including metabolites), OCPs (including metabolites), and the individual pesticides and metabolites. The mean detection frequencies for the pesticide types and their metabolites were as follows: herbicides = 65.9%, insecticides = 76.1%, and fungicides = 69.0%. The most detected class of CUP pesticides were organophosphate insecticides and their metabolites. The pesticides detected in all samples included the CUPs ametryn (herbicide), diuron (herbicide), ethoprophos (insecticide), diazinon (insecticide), fipronil desulfinyl (a metabolite of fipronil which is an insecticide), and the OCPs B-HCH (insecticide) and p,p' DDT (insecticide). The pesticides with the highest mean concentrations for the total sample were diazinon,

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[6] Detection frequency refers to the percentage of wristbands that the pesticide was detected

ethoprophos, p,p’-DDT, and diuron (in ascending order).

In the rural-agricultural SEC, diazinon, ethoprophos, p,p’-DDT, and CIAT (a metabolite of the herbicide atrazine) had the highest DFs and all had higher mean concentrations among girls who lived near pineapple agriculture compared to those who lived near banana plantations, as shown in Table 2. CIAT was detected in the pineapple samples but not in the banana samples. In the rural non-agricultural samples, diuron, p,p’-DDT, ethoprophos, and diazinon were the most frequently detected and had the highest mean concentrations. The pesticides with the highest mean concentrations in the urban samples included diazinon, CIAT, fipronil, and ethoprophos. In the mosaic samples, diazinon, p,p’-DDT, diuron, and boscalid had the highest DFs and concentrations.

Table 2. Summary of Pesticide Detection Frequencies and Concentrations in Silicone Wristbands (ng/g)

		Total Sample		Rural Agricultural						Rural-nonagricultural		Urban/Peri-urban		Mosaic	
				Total		Pineapple Areas		Banana Areas							
Pesticide	**Type**	**Detect %**	**Mean (SD)**	**Detect %**	**Mean (SD)**	**Detect %**	**Mean (SD)**	**Detect %**	**Mean (SD)**	**Detect %**	**Mean (SD)**	**Detect %**	**Mean (SD)**	**Detect %**	**Mean (SD)**
CUPs		100.0%	127.9 (181.3)	100.0%	200.5 (240.1)	100.0%	288.3 (267.5)	100.0%	54.1 (44.4)	100.0%	84.3 (127.4)	100.0%	69.6 (37.5)	100.0%	38.5 (20.7)
Prometon	Herb	37.0%	0.02 (0.0)	37.5%	0.02 (0.02)	60.0%	0.02 (0.0)	0.0%	–	36.4%	0.01 (0.0)	35.7%	0.03 (0.02)	40.0%	0.01 (0.01)
Ametryn[b]	Herb	100.0%	1.6 (1.9)	100.0%	2.0 (2.0)	100.0%	3.1 (1.9)	100.0%	0.3 (0.1)	100.0%	0.3* (0.5)	100.0%	1.9 (2.1)	100.0%	0.9 (0.9)
Diuron[b,c]	Herb	100.0%	13.9 (35.0)	100.0%	10.2 (14.6)	100.0%	13.6 (17.1)	100.0%	4.4 (6.3)	100.0%	**36.3* (72.0)**	100.0%	5.2 (8.4)	100.0%	**6.6 (4.2)**
DCPMU	Metab (Diuron)	72.2%	0.5 (0.5)	75.0%	0.7 (0.5)	93.3%	0.6 (0.5)	44.4%	1.0 (0.6)	63.6%	0.4 (0.7)	71.4%	0.4 (0.5)	80.0%	0.5 (0.2)
Acetochlor[b,c]	Herb	42.6%	0.1 (0.1)	50.0%	0.1 (0.1)	60.0%	0.1 (0.1)	33.3%	0.1 (0.1)	54.5%	0.1 (0.1)	14.3%	0.1 (0.0)	60.0%	0.04 (0.0)
Pendimethalin[c]	Herb	81.5%	0.4 (0.4)	62.5%	0.4 (0.5)	100.0%	0.4 (0.5)	0.0%	–	100.0%	0.2 (0.3)	100.0%	0.5 (0.5)	80.0%	0.4 (0.2)
CIAT	Metab (Atrazine - Herb)	27.8%	17.3 (20.3)	33.3%	**23.2 (25.7)**	53.3%	**23.2 (25.7)**	0.0%	–	45.5%	8.1 (5.2)	14.3%	**16.5 (18.4)**	0.0%	–
Carbaryl[b,c]	Ins	87.0%	0.4 (0.6)	35.2%	0.7 (0.7)	100.0%	0.7 (0.6)	44.4%	0.5 (0.8)	90.9%	0.1 (0.2)	92.9%	0.3 (0.6)	100.0%	0.1 (0.1)
Ethoprophos[b,c]	Ins	100.0%	21.8 (61.8)	100.0%	**35.4 (84.1)**	100.0%	**54.4 (102.9)**	100.0%	3.8 (2.7)	100.0%	**18.5 (54.9)**	100.0%	**7.1 (5.0)**	100.0%	4.3 (4.0)
Malathion[b,c]	Ins	48.1%	0.9 (2.7)	62.5%	0.5 (0.7)	80.0%	0.6 (0.8)	33.3%	0.3 (0.2)	54.5%	2.4 (5.4)	28.6%	0.2 (0.2)	20.0%	0.1 (n/a)
Diazinon[b,c]	Ins	100.0%	69.2 (145.7)	100.0%	**126.5 (205.4)**	100.0%	**191.6 (239.2)**	100.0%	**18.1 (9.7)**	100.0%	**12.5* (16.6)**	100.0%	**34.4 (20.6)**	100.0%	**15.9 (10.6)**
Fipronil[b,c]	Ins	96.3%	4.8 (13.7)	91.7%	3.7 (12.8)	100.0%	5.2 (15.5)	77.8%	0.4 (0.7)	100.0%	2.7 (4.3)	100.0%	**9.7 (20.5)**	100.0%	0.5 (0.3)
Fipronil Desulfinyl	Metab (Fipronil)	100.0%	0.2 (0.63)	100.0%	0.2 (0.8)	100.0%	0.3 (1.0)	100.0%	0.1 (0.1)	100.0%	0.3 (0.7)	100.0%	0.2 (0.4)	100.0%	0.1 (0.0)
Fipronil sulfone	Metab (Fipronil)	98.1%	1.4 (2.27)	95.8%	0.8 (1.8)	100.0%	1.1 (2.2)	88.9%	0.2 (0.2)	100.0%	1.5 (1.9)	100.0%	2.3 (3.3)	100.0%	0.7 (0.2)
DETP	Metab (organo-phosphate-Ins)	31.5%	1.0 (0.7)	8.3%	0.7 (0.1)	13.3%	0.7 (0.1)	0%	–	36.4%	0.3 (0.1)	57.1%	1.3 (0.8)	60.0%	1.2 (0.5)
Metalaxyl[c]	Fung	81.5%	0.2 (0.3)	83.3%	0.2 (0.2)	100.0%	0.2 (0.2)	55.6%	0.05 (0.0)	63.6%	0.3 (0.7)	85.7%	0.2 (0.2)	100.0%	0.1 (0.1)
Azoxystrobin	Fung	96.3%	3.8 (13.7)	100.0%	7.2 (19.8)	100.0%	0.6 (0.6)	100.0%	**18.1 (30.2)**	81.8%	0.3 (0.1)	100.0%	1.4 (1.2)	100.0%	1.0 (0.7)
Myclobutanil	Fung	38.9%	0.6 (1.6)	45.8%	1.0 (2.1)	26.7%	0.04 (0.0)	77.8%	1.6 (2.6)	18.2%	0.1 (0.0)	35.7%	0.2 (0.1)	60%	0.1 (0.0)
Boscalid	Fung	87.0%	2.1 (5.0)	83.3%	2.8 (6.0)	73.3%	0.5 (0.6)	100.0%	**5.7 (8.3)**	72.7%	0.2 (0.2)	100.0%	1.0 (0.5)	100.0%	**5.7 (9.4)**
Tebuconazole[c]	Fung	40.7%	0.3 (1.1)	45.8%	0.05 (0.8)	60.0%	0.1 (0.0)	22.2%	0.03 (0.0)	9.1%	0.03 (n/a)	35.7%	1.1 (2.2)	100.0%	0.1 (0.0)
Propiconazole[b,c]	Fung	74.1%	0.3 (0.6)	70.8%	0.5 (0.8)	93.3%	0.3 (0.5)	33.3%	1.1 (1.8)	63.6%	0.1 (0.1)	85.7%	0.2 (0.2)	80.0%	0.1 (0.1)
Pyraclostrobin	Fung	81.5%	0.1 (0.1)	75.0%	0.1 (0.1)	66.7%	0.1 (0.1)	88.9%	0.1 (0.1)	81.8%	0.1 (0.0)	92.9%	0.2 (0.1)	80.0%	0.2 (0.2)

OCPs	N = 52	100.0%	25.7 (37.6)	100.0%	36.1 (49.0)	100.0%	41.8 (52.6)	100.0%	23.8^{3} (41.1)	100.0%	29.2 (36.3)	100.0%	8.1 (3.6)	100.0%	21.9 (19.2)
B-HCH^{a,b,c}	Ins	100%	0.1 (0.2)	100%	0.02 (0.0)	100.0%	0.3 (0.0)	100.0%	0.2 (0.0)	100.0%	0.02 (0.0)	100.0%	0.2* (0.4)	100.0%	0.02 (0.0)
G-Chlordane^{a,b,c}	Ins	25.00%	0.6 (0.5)	40.90%	0.7 (0.5)	53.3%	0.7 (0.6)	14.3%	0.4 (n/a)	0.0%	–	28.6%	0.3 (0.2)	0.0%	–
T-Nona^{a,b,c}	Ins	82.70%	1.6 (1.0)	81.80%	1.6 (0.7)	93.3%	1.5 (0.6)	57.1%	1.9 (0.8)	72.7%	1.9 (1.9)	92.9%	1.4 (0.7)	80.0%	2.0 (1.3)
o,p'-DDT^{a,b,c}	Ins	34.60%	2.5 (1.7)	40.90%	2.5 (1.8)	60.0%	2.5 (1.8)	0.0%	–	18.2%	1.9 (0.0)	21.4%	1.2 (0.6)	80.0%	3.7 (1.4)
p,p'- DDT^{a,b,c}	Ins	100%	17.5 (34.2)	100%	**23.4 (44.2)**	100.0%	**32.0 (51.7)**	100.0%	**4.9 (4.3)**	100.0%	**24.6 (36.1)**	100.0%	3.7 (3.1)	100.0%	**14.7 (19.5)**
p,p'-DDE	Metab (DDT)	90.40%	1.4 (0.9)	95.50%	1.2 (0.5)	100.0%	1.2 (0.5)	85.7%	1.2 (0.5)	72.7%	1.0 (0.7)	100.0%	1.7 (1.1)	80.0%	2.4 (1.9)
p,p'-DDD	Metab (DDT)	48.10%	1.2 (0.8)	45.50%	1.6 (1.1)	66.7%	1.6 (1.1)	0.0%	–	81.8%	0.9 (0.4)	35.7%	0.9 (0.6)	20.0%	0.8 (n/a)
Heptachlor epoxide	Metab (Heptachlor-Ins)	38.5%	0.34 (0.43)	45.5%	0.67 (0.39)	66.7%	0.67 (0.39)	0.0%	–	0.0%	–	50.0%	0.01 (0.0)	60.0%	0.01 (0.0)
HCB^{a,b,c}	Fung	51.90%	0.2 (0.2)	4.5%	0.6 (n/a)	6.7%	0.6 (n/a)	0.0%	–	100.0%	0.3 (0.3)	71.4%	0.2 (0.1)	100.0%	0.1 (0.1)
Total Pesticides		96.30%	157.3 (192.9)	91.70%	251.8 (254.3)	100.0%	330.1 (274.3)	77.8%	84.1	100.0%	113.5 (129.5)	100.0%	77.6 (37.3)	100.0%	60.3 (18.4)

Detect = detection; CUPs = Current-use Pesticides; OCPs = Organochlorine Pesticides

^{a} banned by the Stockholm Convention (UN, n.d.); ^{b} banned or not approved by the European Union (PAN International, 2022); ^{c} banned by one or more countries according to the PAN International Consolidated List of Banned Pesticides (PAN International, 2022)

DETP = Diethylthiophosphate, a metabolite of organophosphate pesticides typically insecticides

CIAT = 2-chloro-4-isopropylamino-6-amino-s-triazine, commonly known as deethylatrazine, a metabolite of atrazine

DCPMU = N-Demethoxylinuron (AKA: Diuron-desmethyl), metabolite of Diuron

B-HCH = β-Hexachlorocyclohexane

G-Chlordane = gamma-chlordane

T-Nona = trans-nonachlor

p,p'-DDE = 4,4'-Dichlorodiphenyldichloroethylene, metabolite of DDT

p,p'-DDD = 4,4'-Dichlorodiphenyldichloroethane, metabolite of DDT

o,p'-DDT = 2,4'-Dichlorodiphenyltrichloroethane

p,p'-DDT = 4,4'-Dichlorodiphenyltrichloroethane

HCB = Hexachlorobenzene

INS = insecticide; HERB = herbicide; FUNG = fungicide; METAB = metabolite

Bolded quantities indicate the highest (4) for each SEC

^{3}Mean OCPs is higher compared to the individual OCP detection means for the banana SEC due to one sample having a high detection of A-chlordane (111.4 ng/g).

Alpha <0.05, *p <0.05, **p<0.01, ***p<0.001; $^{+}$Base comparison: rural agricultural SEC

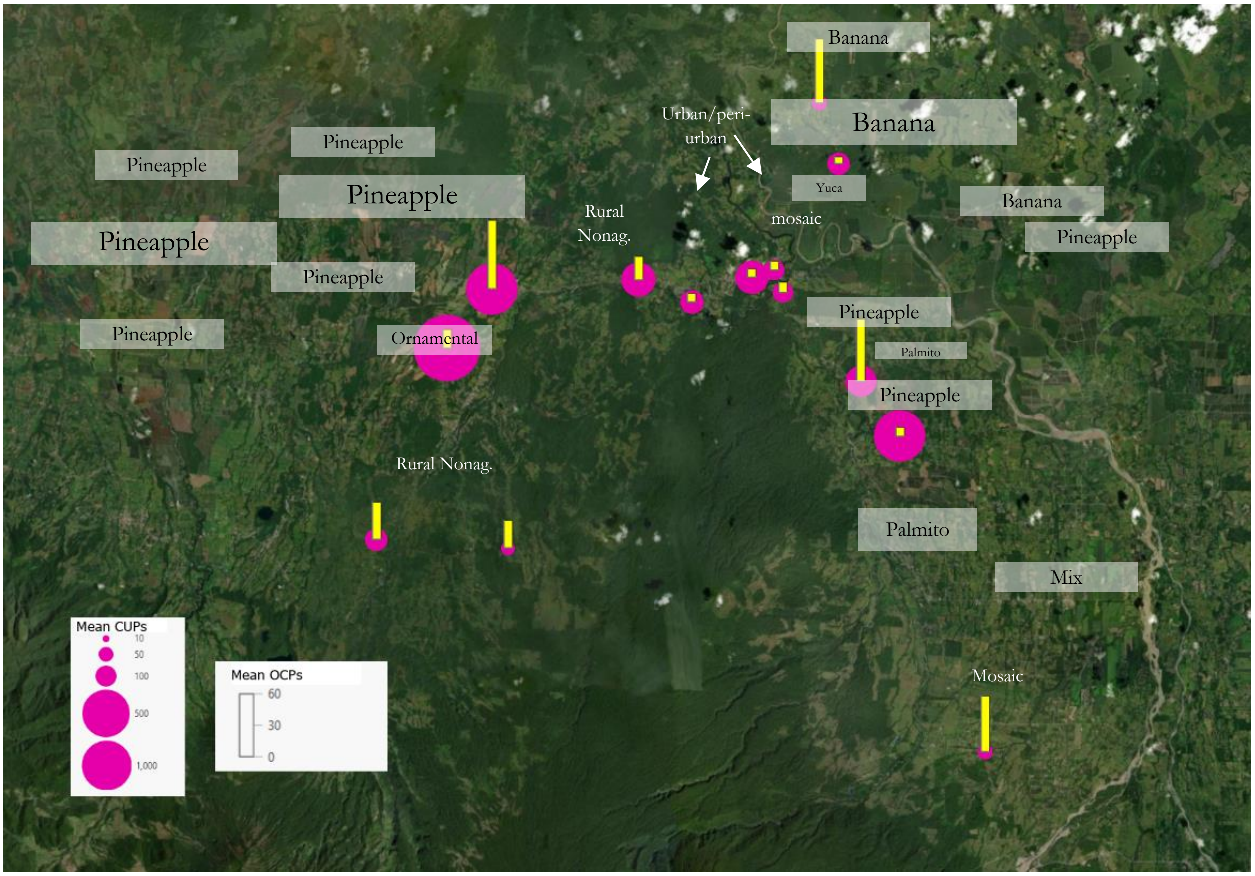

Figure 1. Satellite map of the mean total CUPs and total OCPs, including their metabolites, per sampling communities. Mean total CUPs are indicated by pink circles, where larger circles reference larger means. Mean total OCPs are referenced with yellow bars, with taller bars indicating larger means. The major commodity that is grown near the community and the urban/peri-urban, rural nonagricultural (Nonag.), and mosaic SECs are also labeled.

Pesticides and SECs

Exposure to pesticides varied across the four SECs, as shown in Table 1 and in the map in Figure 1. Total pesticide concentrations were highest among girls from agricultural communities, followed by those living in rural non-agricultural areas characterized by forest or pasture. According to regression analysis (using log transformations of pesticide data), samples from rural nonagricultural and mosaic SECs had significantly lower concentrations of CUPs compared to the agricultural samples (B = -1.0, *p* = 0.010; B = -1.2, *p* = 0.030, *respectively*), but only samples from urban/peri-urban communities had significantly lower concentrations of OCPs compared to the agricultural samples (B = -0.9, $p = 0.033$). For more data visualization, see the heat maps (Figures S1 and S2) in the supplementary materials.

Among the pesticides with 100% DFs, ametryn was significantly lower among rural nonagricultural samples compared to agricultural participants (B = -1.6, $p < 0.001$), and ethoprophos and diazinon were significantly lower among rural nonagricultural (B = -1.7, $p =$ 0.001; B = -1.9, $p <0.001$, *respectively*) and mosaic samples (B = -1.4, $p = 0.029$; B = -1.4, $p =$ 0.19, *respectively*) compared to agricultural samples. Β-HCH was higher among urban/peri-urban samples compared to agricultural (B = 0.6, $p = 0.014$). Diuron, desulfinyl fipronil and p,p'DDT did not vary by SEC.

Pesticides and Individual Characteristics

Pesticide exposure did not significantly differ among the household demographic categories, including whether a member of the household worked in plantation agriculture, or by perceptions of whether pesticides are used nearby and worry about pesticide exposure when using log transformations.

Pesticides and Distance to Plantations

Distance to any large-scale monoculture fields (km≤3) was negatively correlated with CUP concentrations ($r^2 = 0.1$, $p = 0.010$)(Figure 2). CUP concentrations were also negatively correlated with distance to pineapple plantations (km) ($r^2 = 0.2$, $p = 0.001$)(Figure 3), but not with distance to banana plantations (Figure 4). OCP concentrations were not correlated with distance to any large-scale agriculture or proximity to pineapple or banana monoculture, specifically. Neither CUPs nor OCPs were associated with distance to forest.

Among the pesticides with 100% DF, ametryn was negatively correlated with distance to any large-scale agriculture and distance to pineapple plantations, specifically ($r^2 = 0.1$, $p = 0.019$; $r^2 = 0.2$, $p < 0.001$, *respectively*). Ethoprophos negatively correlated with distance to any large-scale agriculture and distance to pineapple fields ($r^2 = 0.2$, $p = 0.002$; $r^2 = 0.3$, $p < 0.001$, *respectively).* Diazinon also negatively correlated with distance to any large-scale agricultural plot and distance to pineapple agriculture ($r^2 = 0.1$, $p = 0.016$; $r^2 = 0.2$, $p < 0.001$). No individual pesticide was correlated with distance to banana fields.

Table 3. B Coefficients and CIs for independent variables significantly predicting log-transformed pesticide concentrations in linear regression

Independent Variable	CUPs	OCPs	Ametryn	Etho-prophos	Diazinon	BHCH
Social-Ecological Context						
+Rural Agricultural	--	--	--	--	--	--
Rural Nonagricultural	-1.0* (-1.8, -0.3)	-0.4 (-1.3, 0.5)	-1.6*** (-2.4, -0.7)	-1.7** (-2.6, -0.7)	-1.9*** (-2.8, -1.1)	0.0 (-0.5, 0.6)
Urban-Peri Urban	-0.5 (-1.3, 0.2)	-0.9* (-1.7, -0.1)	0.0 (-0.7, 0.8)	-0.6 (-1.5, -.2)	-0.5 (-1.3, 0.3)	0.6* (0.1, 1.2)
Mosaic Agriculture-Forest	-1.2* (-2.2, -0.1)	-0.1 (-1.3, 1.1)	-0.6 (-1.7, -0.5)	-1.4* (-2.7, -0.2)	-1.4* (-2.5, -0.2)	-0.1 (-0.8, 0.6)
Distance to Large-scale Agriculture	-0.5* (-0.9, -0.1)	-0.1 (-0.5, 0.2)	-0.05* (-1.0, -0.1)	-0.8** (-1.2, -0.3)	-0.6* (-1.1, -0.1)	-0.0 (-0.3, 0.2)
Distance to Pineapple Agriculture	-0.2** (-0.3, -0.1)	-0.1 (-0.3, 0.0)	-0.2*** (-0.4, -0.1)	-0.3*** (-0.5, -0.2)	-0.3*** (-0.4, -0.1)	0.1 (-0.0, 0.2)

Alpha <0.05, *p <0.05, **p<0.01, ***p<0.001
CUPs = current-use pesticides, OCPs = organochlorine pesticides
+Base comparison variables: rural agricultural SEC

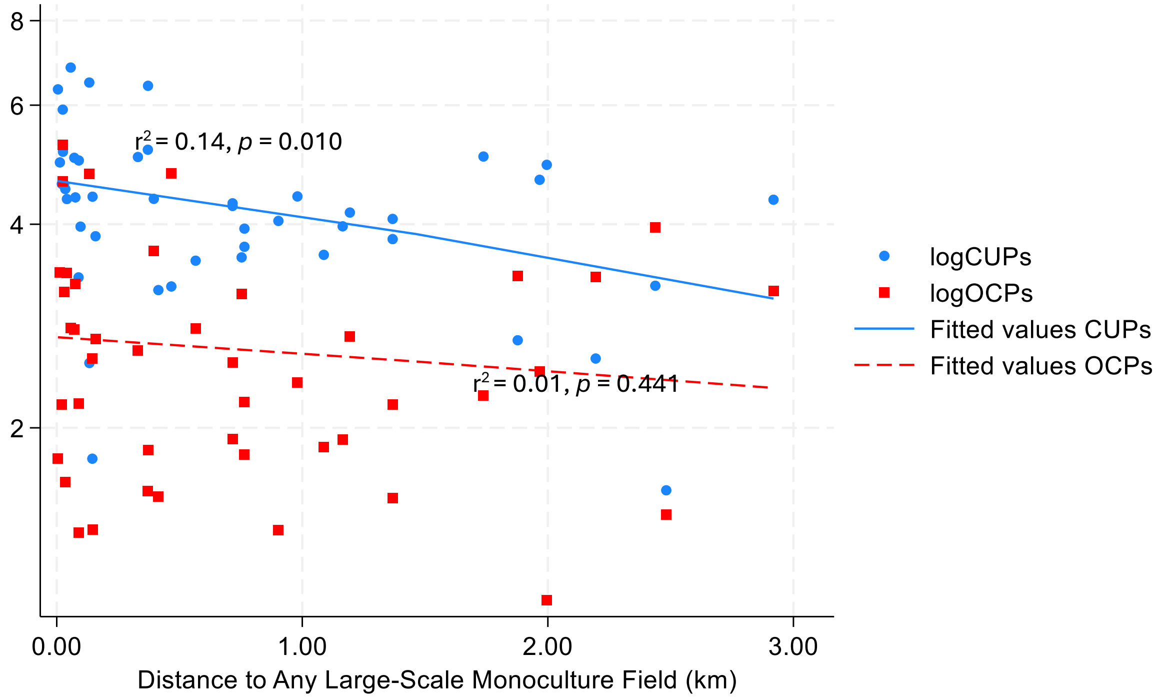

Figure 2. Scatterplot with logarithmic scale on the y axis showing the relationship between pesticide concentrations and distance to any large-scale agriculture. CUPs: individual concentrations are indicated by blue circles and the fitted values are represented by a solid blue line. OCPs: individual concentrations are indicated by red squares and the fitted values are represented by a red dashed line.

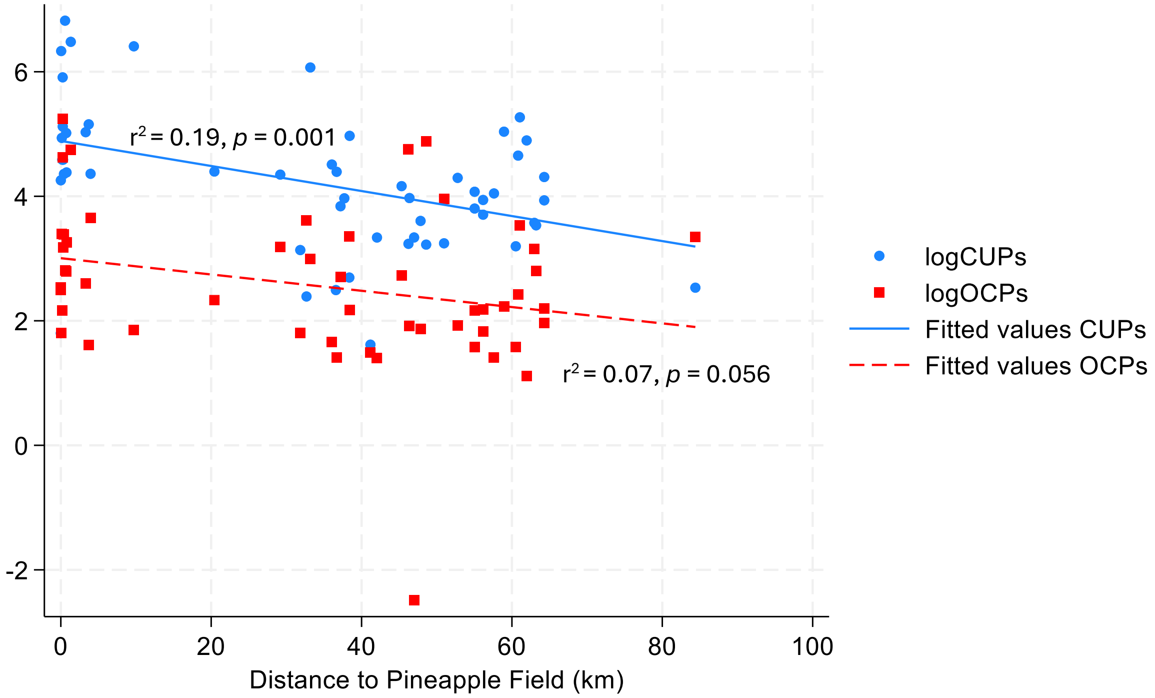

Figure 3. Scatterplot with logarithmic scale on the y axis showing the relationship between pesticide concentrations and distance to pineapple fields. CUPs: individual concentrations are indicated by blue circles and the fitted values are represented by a solid blue line. OCPs: individual concentrations are indicated by red squares and the fitted values are represented by a red dashed line.

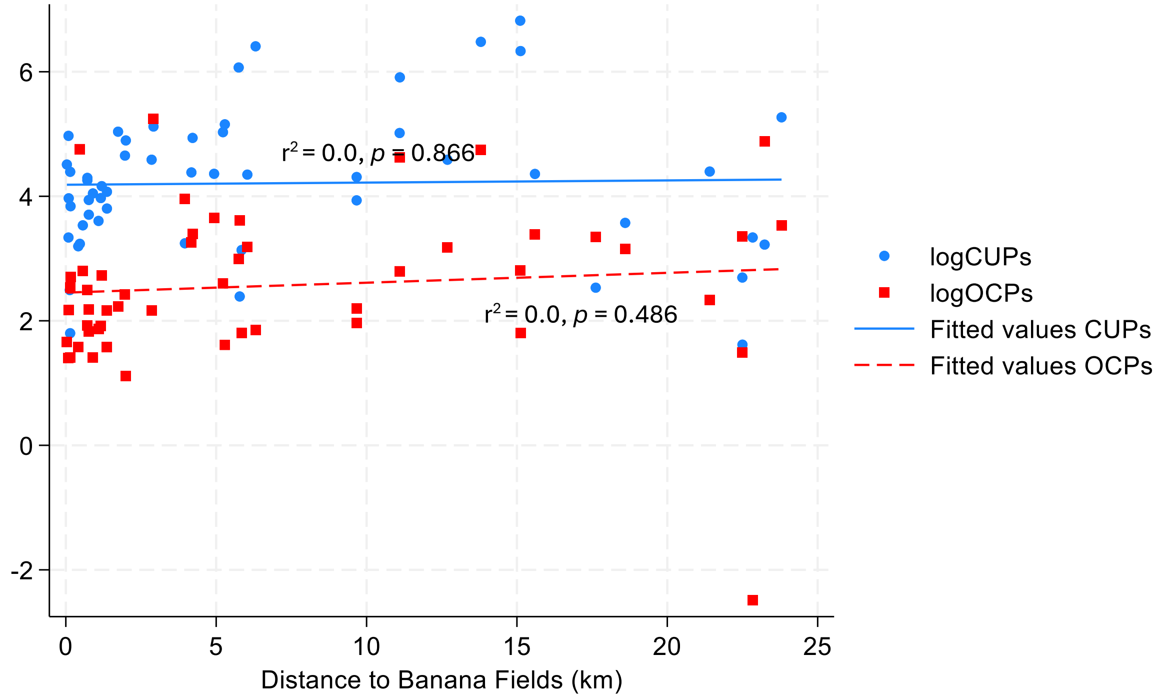

Figure 4. Scatterplot with logarithmic scale on the y axis showing the relationship between pesticide concentrations and distance to banana fields. CUPs: individual concentrations are indicated by blue circles and the fitted values are represented by a solid blue line. OCPs: individual concentrations are indicated by red squares and the fitted values are represented by a red dashed line.

Multivariate Analyses

Relationship of Predictor Variables

Distance to any large-scale agriculture and distance to pineapple agriculture, specifically, were positively correlated ($r^2 = 0.2$, $p = <0.001$). Rural nonagricultural, urban/peri-urban, and mosaic SECs were significantly farther from any large-scale field and pineapple agriculture, specifically, than the agricultural samples ($p < 0.001$; $p < 0.001$; $p = 0.001$, *respectively*).

Discussion

Detection frequencies for insecticides, herbicides, and fungicides were similar across the entire sample. The wristbands detected higher frequencies and quantities of CUPs compared to

OCPs. However, mean exposure levels to the OCP p,p'-DDT were similar to that of CUPs and detected in all samples. Comparing SECs, the rural agricultural communities had the highest concentrations overall, and agricultural samples were associated with higher concentrations of the CUPs ametryn, ethoprophos, and diazinon when compared to nonagricultural samples. Ethoprophos and diazinon were also higher in mosaic communities that have a mix of agriculture and forest compared to the samples from agricultural communities. OCP concentrations were negatively related to living in urban areas compared to agricultural areas.

Household factors, including occupational exposure through household members' employment in pineapple and banana plantations, and perceptions of pesticide exposure did not predict exposure in this sample. Therefore, secondary exposure and household characteristics such as socioeconomic status are not the primary causes of girls' exposure in this sample. This is in contrast with existing literature that shows higher pesticide exposure among individuals who work in conventional agriculture in Costa Rica (Alvarado-Prado et al., 2022; Mora et al., 2014). However, a study from Talamanca, Costa Rica indicated that parental occupation was not associated with pesticide levels among children (van Wendel de Joode et al., 2016). It may be that agribusinesses are abiding by the Guide for Occupational Health for Agricultural Workers presented by Costa Rica's Ministry of Employment and Social Security, which requires the training in safe handling and storage of agrochemicals, protective equipment and clothing be worn by applicators, and applicators bath and change after each application (Guía de Salud Ocupacional En La Agricultura, n.d.). If these preventive measures are being followed, we would not expect household members' employment in the plantations to contribute to the pesticide exposure load of homes. Further research should obtain information on occupational behaviors as well as whether household members use pesticides residentially.

We found support for our prediction that proximity to industrial agriculture, particularly pineapple fields, on total CUP exposure as well as exposure to specific CUPs (ametryn, ethoprophos, and diazinon). We detected many more pesticides associated with pineapple agriculture than banana operations. The pesticides most widely reported for banana agriculture that we detected in our sample (>25% DF) included ethoprophos, azoxystrobin, and tebuconazole. Those that are registered as most used for pineapple cultivation that we detected (>25% DF) were ametryn, diuron, diazinon, carbaryl, ethoprophos, metalaxyl, and propiconazole (Vargas Céspedes et al., 2018). Similarly, both CUPs and OCPs were higher in samples from pineapple communities compared to samples from banana areas. Thus, our data suggests that pineapple agribusinesses in Sarapiquí are associated with higher levels of environmental contamination of pesticides and subsequent exposures by community members than other commodity crops including banana.

While there have not been any other comparative analyses of environmental pesticide levels/exposure related to different types of monoculture businesses (to our knowledge), the University of Costa Rica detected CUPs in surface waters near pineapple plantations in the province of San Carlos (Sarapiquí's western neighbor), and the National University of Costa Rica states diuron has been measured in surface waters in the pineapple zones of Sarapiquí (UNA & IRET, n.d.-a). Despite a lack of research near pineapple fields in Sarapiquí, there have been many complaints filed regarding water pollution and invasion of protected areas by the pineapple agroindustry in the region (Consejo Univesitario de la Universidad de Costa Rica, 2018).

Lower quantities of pesticides were detected in wristbands worn by girls in banana communities compared to other SECs, with the exception of the fungicide azoxystrobin. Relatedly, distance to banana agriculture was not associated with CUP or OCP exposure including in assessments of individual pesticides detected at 100% DFs. Since this is the first the study to assess personal pesticide exposure using wristbands among Costa Rican samples, we cannot directly compare our findings to previous investigations using environmental samples. However, investigators have detected higher levels of pesticides in urinary samples among women and children who lived close to banana plantations in Limón compared to those who lived farther away (van Wendel de Joode et al., 2014, 2016). Furthermore, investigations assessing environmental samples have found pesticides near banana plantations in Limón, the province directly east of Sarapiquí. For example, pesticides were detected in water channels that connect banana plantations to natural bodies of water as well as in natural rivers and lakes, soil samples, and air samples in banana growing regions (Brühl et al., 2023; Córdoba Gamboa et al., 2020; Echeverría-Sáenz et al., 2021). These included the CUPs ametryn, diuron, carbaryl, diazinon, ethoprophos, metalaxyl, azoxystrobin, and boscalid—pesticides that we also detected in our sample using silicone wristbands (Bruhl et al., 2023; Echeverria-Saenz et al., 2021). This is consistent with another study showing exposure to propiconazole near banana fields and bromacil in banana and pineapple zones (Castillo et al., 2000; Fonseca & Vargas, 2020; UNA & IRET, n.d.-c).

Banana plantations use mixed application methods. Typically, fungicides are sprayed aerially whereas insecticides, including nematicides, are applied at the base of the plant and through impregnated bags that wrap around the fruit (Brühl et al., 2023; Smilanich & Dyer, 2012; Vargas Céspedes et al., 2017). Pineapple plantations, on the other hand, spray all types of pesticides with large tractors. The different techniques may help explain why samples taken near pineapple crops had overall higher detection levels but samples from banana communities had higher fungicide levels. Similarly, application practices may contribute to the consistent correlations between CUP concentrations and proximity to pineapple plantations. There are higher levels of CUPs in the environments closest to pineapple operations in Sarapiquí. In non-pineapple communities, CUP exposure is more complicated and may be dependent on the number of adults in the home in combination with distance to any large-scale agriculture and SEC. We don't believe public health fumigation campaigns were a large factor in exposure to CUPs in this sample as we found low detection frequencies (<25%) for the primary insecticides used for the mitigation of mosquito-borne diseases according to the Ministry of Health (primary insecticides for public health interventions: pyrethroids (e.g., alphacypermethrin and permethrin) and the organophosphate temephos (Costa Rica Ministry of Health, 2021)). Furthermore, children in the sample wore wristbands when traveling to school. While age and grade level were not associated with exposure to any of the pesticide variables, the two main high schools are located in different SECs, where one is near banana fields and the other is closer to pineapple and other types of commodities such as black pepper and ornamental plants.

Total OCP concentrations were significantly lower among urban/peri-urban samples compared to rural agricultural samples as well as among girls with caretakers from Nicaragua compared to those with caretakers born in Costa Rica. This indicates variation in atmospheric exposure based on social-ecological context. However, it is also likely related to the history of the various landscapes and their use of historical use of OCPs. Many pesticides accumulate in soils, sediments, and forests due to the forest filter effect (Chaudhari et al., 2023; Echeverría-Sáenz et al., 2021; Mandal et al., 2020; Mclachlan & Horstmann, 1998). OCPs, including B-HCH, chlordane, DDT, and HCB, are among the most environmentally persistent agrochemicals (Mandal et al., 2020). Thus, girls in this sample living in areas that have been engaged in agriculture and pesticide application for decades may be exposed to OCPs even if they have not been in use for many years.

However, it is important to make note of the high concentrations of DDT in comparison to other highly persistent OCPs in combination with the detection of DDT breakdown products (DDE and DDD). While only indicative of air exposure (a proxy for inhalation), a 2019 analysis of air samplers from the Braulio Carrillo National Forest in Sarapiquí found much lower concentrations for DDT (median = 1.4) compared to our sample (Wang et al., 2019) . This may infer recent utilization, although it is also expected that wristbands will provide a more representative measure of environmental exposure through their ability to sequester chemicals through various exposure means, not just air (i.e. inhalation).

Fumigation for malaria control is one probable reason for the relatively high concentrations of p,p’ DDT in this sample compared to Wang et al. and other detected OCPs. Following the recommendations of the World Health Organization (WHO), the Costa Rican Ministry of Health approves the use of DDT for malaria outbreaks. Because of past intensive fumigation campaigns, malaria has not been a concern in Costa Rica for decades (Rehwagen, 2006). However, it is reemerging as a result of climate change and globalization factors (*CDC* -

Malaria - Costa Rica, n.d.; Rehwagen, 2006). The Huetar Norte region represented 90% of malaria cases in the spring of 2022–when the wristbands were deployed–resulting in simultaneous elimination efforts in the region (Fernandez, 2022; Organisation panaméricaine de la santé, 2022). More specifically, reports document that public health workers fumigated around homes in active areas (Fernandez, 2022). Therefore, the lack of significant variation in relation to proximity to agriculture may be the result of concurrent fumigation of DDT near the time of the study in combination with intensive past use that has resulted in an accumulation of DDT in the environments. These factors can also speak to why the highest mean concentrations for p,p' DDT were found in the nonagricultural samples (e.g., forest and pastures) and near pineapple plantations—areas that tend to have stagnant water and probable sites for mosquito nesting and breeding which would motivate fumigation efforts.

Lastly, we did not find associations between distance to forest and pesticide exposure in this sample. The forest filter effect refers to the ability of temperate forests to transfer organic chemicals from the atmosphere to the soil, subsequently reducing atmospheric exposure (Barrett et al., 2019; Barrett & Jaward, 2020). This effect can lead to increased levels of water-soluble chemicals in surface water through run-off, especially in rainy areas like Sarapiquí (Barrett et al., 2019; Barrett & Jaward, 2020). Thus, we may expect to find a balancing effect in the wristbands of girls living near forest, where atmospheric exposure may be less (supporting the low levels in Wang et al., 2019) but exposure through water may be higher if their water source differs compared to samples from non-forested areas. Conversely, we would anticipate similar exposure levels from water, and therefore lower overall variation in exposure if participants share polluted watersheds.

This is the first study using silicone wristbands to measure personal exposure to pesticides in Costa Rica. Only two other investigations have published similar work. Donald et al., (2016) provided the first published report of pesticide concentrations using silicone wristbands among a sample of adult farmworkers in West Africa (Donald et al., 2016). They tested for 63 pesticides/metabolites, including legacy OCPs and current-use chemicals. However, only 35 out of 70 participants obtained 100% compliance and only detected 26 pesticides overall (Donald et al., 2016). The most frequently detected pesticides differed from our study possibly due to differences in the crops grown although the article does not provide any contextual information regarding agricultural operations or scale (Donald et al., 2016). They also do not provide summary statistics for the pesticides detected, making it nearly impossible to compare our data to theirs.

In Harley et al., (2019), researchers explored 10 legacy- and 15 current-use pesticides/metabolites used in agriculture and/or residentially among girls aged 14 to 16 in an agricultural region of California. The study tested for much fewer pesticides and metabolites (e.g., did not test for some persistent organochlorine pesticides like DDT and Lindane) compared to the dissertation and Donald et al., did not use log-transformations of the data, and detection frequencies were on average lower than those presented in this dissertation (only one pesticide, Fipronil sulfide, was detected at above 56%)(Harley et al., 2019). Similar to Harley et al., fipronil metabolites were also among the most frequently detected in our sample, but we cannot directly compare means because we tested for fipronil sulfone versus sulfide. The additional pesticides most detected in Harley et al. do not match those from our research, likely due to variation in the crops grown as well as ecological differences that result in differences in pests and crop-disease risks. However, our findings that proximity to agricultural fields align with those of Haley et al. which documented higher mean concentrations of pesticides among wristbands from girls who lived within 100 meters of active agricultural fields (Harley et al., 2019).

Limitations

A limitation of this analysis is the small size of the subsample, which was limited due to budgetary constraints; 137 more wristbands are available for future analysis. Because this study focused on girls and their experiences, we did not collect information from household members (such as behaviors) that could provide further insights into household pesticide exposure. Lastly, because the wristbands capture exposures from inhalation and dermal absorption but not ingestion, we cannot speak directly to the specific sources of pesticide exposure in this sample and the total exposure levels may be higher than what is measured here. However, our consistent finding that living near agricultural operations, especially pineapple fields, increases exposure among children and adolescents provides support for intervention strategies related to atmospheric contact and application practices. Additionally, the relatively high compliance, detection frequencies, and expansiveness of the pesticides tested for and detected in this dissertation makes important headway in the development of a reference dataset for continued work. The findings should be considered in agricultural, environmental, and public health policy initiatives.

Implications

In conclusion, our analysis shows that household characteristics including household size, household members’ occupations in the pineapple and banana industries, income, and time lived at current residency did not determine exposure to CUPs or OCPs among children and adolescents in this sample. This suggests that community members are vulnerable to exposure despite social status and household members' occupations. Furthermore, distance to any large-scale monoculture field and particularly pineapple fields strongly contributed to variation in exposure levels of CUPs, including ametryn, ethoprophos, and diazinon, which are highly toxic and banned by numerous other countries (PAN, 2022). Therefore, in this sample, we find evidence that girls living nearest to pineapple agriculture are most susceptible to exposure to current-use pesticides. Living in a rural agricultural SEC more generally was significantly related to closer proximity to monoculture fields. These findings, in combination with the fact that household members' employment in agriculture was not associated with girls' exposure levels, infers that exposure is largely environmental and likely related to atmospheric drift and/or water pollution of CUPs. These spatial inequalities must be considered in policy, regulations, and mitigation efforts.

Exposure to OCPs was not associated with proximity to agriculture and levels were similar across the SECs apart from lower concentrations among the urban samples. Thus, girls may be exposed through non-atmospheric avenues and/or persistence in soils and sediments. However, the concentrations detected for OCPs were largely driven by exposure to p,p' DDT which is recommended for malaria mitigation campaigns. Further research is necessary to better understand the environmental avenues of exposure to pesticides including comparative analyses of water, air, produce, and dust samples combined with data on household water sources and use across the different SECs.

Nearly all the pesticides detected at the highest frequencies and quantities across the

SECs are banned in the E.U. and other countries according to the PAN International consolidated list of banned pesticides (PAN, 2022; Pesticides Action Network Europe, 2020). These pesticides are prohibited due to substantial evidence of their health hazards, including acute toxicity and associations with chronic diseases. Among those detected in all samples, ametryn is labeled with acute toxic level 4 by the European Chemicals Agency (ECHA)(National Library of Medicine, n.d.-a) and moderately hazardous (class 2) by the World Health Organization(WHO, 2019). High exposure levels have been associated with oxidative stress and cardiovascular and musculoskeletal abnormalities in zebrafish (Lin et al., 2018; Moura et al., 2018) and chromosomal defects and sperm reduction in rats (Dantas et al., 2015; Santos et al., 2015). Ethoprophos is classified as extremely hazardous (class 1) by the WHO and the United States Environmental Protection Agency (EPA) (National Library of Medicine, n.d.-d; WHO, 2019) and highly dangerous by the Costa Rican Ministry of Agriculture and Livestock (MAG) (Servicio Fitosanitario del Estado, 2024). It is among the pesticides most responsible for fatalities in Costa Rica (Rojas, 2016). Ethoprophos is considered a probable carcinogen and has been connected to genetic damage among adults, cardiac toxicity in zebrafish, and increased chromosomal abnormalities in mice (Alvarado-Prado et al., 2022; El-Gendy et al., 2023; Kaur et al., 2018; Li et al., 2021). The WHO classifies diazinon as moderately hazardous (class 2), but it is categorized as highly dangerous by the Costa Rican MAG (Servicio Fitosanitario del Estado, 2024; WHO, 2019). Chronic exposure has been associated with neurotoxicity, increased genetic mutations, endocrine disruption, asthma, autism spectrum disorders, chronic bronchitis, liver damage, cognitive disorders, depression, diabetes, fibrosis, hemorrhage, hepatitis, hyperglycemia, hypotension, hypothyroidism, male infertility, inflammation, insulin resistance, leukemia, lung tumor, lymphoma , intellectual. Disability, memory disorders, pancreatic diseases, Parkinson’s, rhinitis, seizures and tremors (National Library of Medicine, n.d.-c). Diuron is classified as slightly hazardous (class II) and long-term or high level exposure has been associated with hyperplasia, reduction in red blood cell count, inflammation, liver enlargement and damage, urinary bladder disease, and bladder neoplasms in studies among rats and dogs (Australian Pesticides and Veterinary Medicines Authority, 2011). While only classified as moderately hazardous (class II), B-HCH (beta- hexachlorocyclohexane) is among the POPs banned by the Stockholm Convention and Costa Rica since the early 2000s. Chronic exposure is associated with an abundance of diseases including Alzheimer’s, liver and kidney disease, Parkinson’s, hepatitis, eczema, rhinitis, anemia, and potential cancer including brain cancer (National Library of Medicine, n.d.-e; WHO, 2019). Lastly, DDT, also banned by the Stockholm Convention and even earlier in Costa Rica, is among the most investigated and documented pesticides related to health consequences. Studies show long-term exposure is associated with neurotoxicity, psychological depression, dermatitis, human cancer particularly liver and leukemia, endocrine disruption, Parkinson’s, risk of diabetes, embryo loss, precancerous cell formation, hypertension, insulin resistance, chromosomal disorders, congenital anomalies, premature birth, seizures, and fatty liver disease (Ishikawa et al., 2015; National Library of Medicine, n.d.-b; Universidad Nacional de Costa Rica, n.d.). An investigation among Costa Rican public health workers who applied DDT to combat malaria found a connection to exposure and neurological damage (Universidad Nacional de Costa Rica, n.d.).

The risks of pesticide exposure among children are even more serious. Infants and children are more vulnerable to chemical exposure for a variety of factors. Their lower stature increases their proximity to heavier chemicals that accumulate closer to the surface and those that reside in dust and soils (Mastorci et al., 2021). Toddler and child behaviors such as crawling and/or playing on the ground/floor and spending time outdoors—both culturally normative and common in the context of Costa Rica—can also increase exposure (Mastorci et al., 2021). In addition, children ingest more food and air relative to their body size compared to adults. Exposure during childhood, in general, is associated with a higher risk of developmental abnormalities, neurobehavioral defects, and endocrine disruption which can alter maturation and induce further associated risks for adult-onset diseases including cancer (Alvarado-Prado et al., 2022; Brühl et al., 2023; Gore et al., 2015; Sarkar et al., 2021; van Wendel de Joode et al., 2016). For females specifically, reproductive organs (e.g., mammary glands, ovaries, and uterus) are more susceptible to EDCs during pubertal development, and, therefore, exposure during this critical period can greatly increase the risk for endocrine disruption and subsequently reproductive disorders and cancer (Gore et al., 2015). Therefore, we encourage policymakers to better regulate or restrict the use of these dangerous pesticides to protect children and adolescents from the long-term consequences that exposure may cause.

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Supplementary Materials

Figure S1

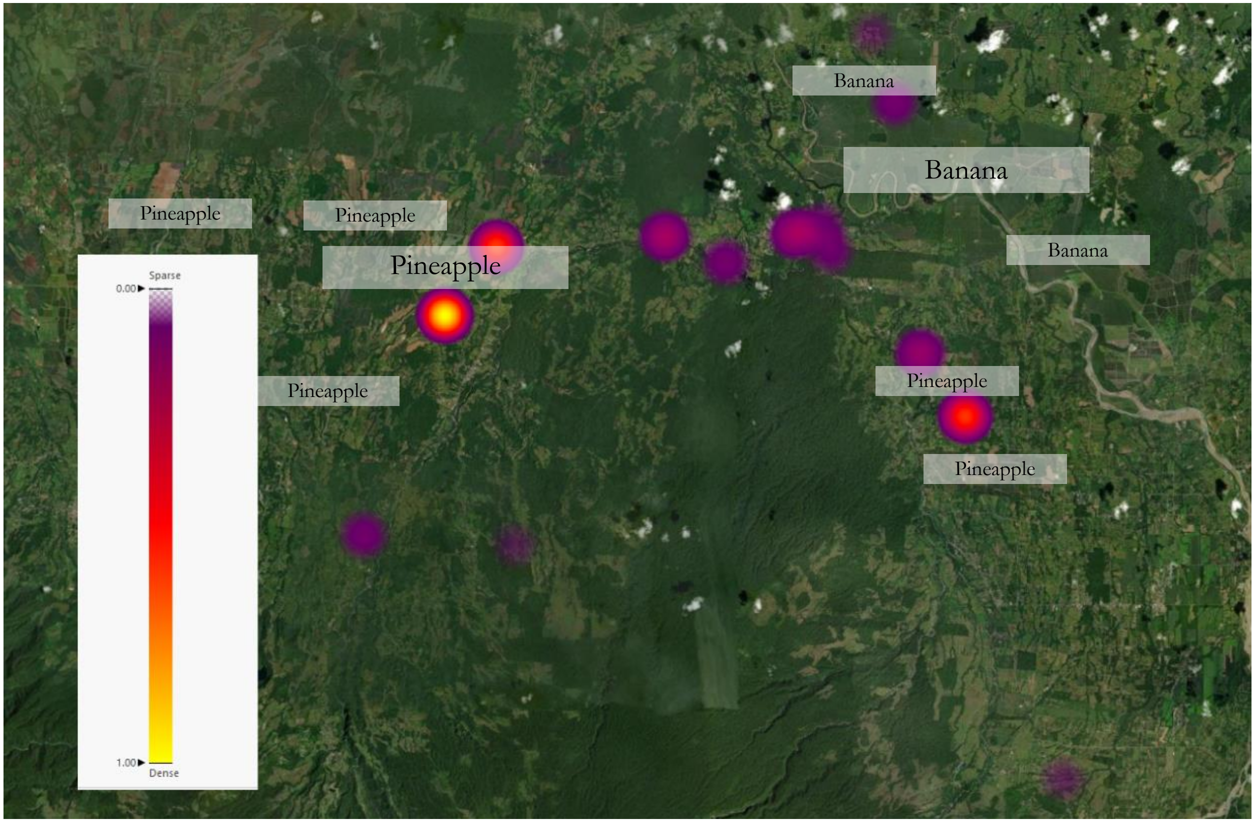

Figure S 1. Heat density map of mean total CUPs

Figure S2

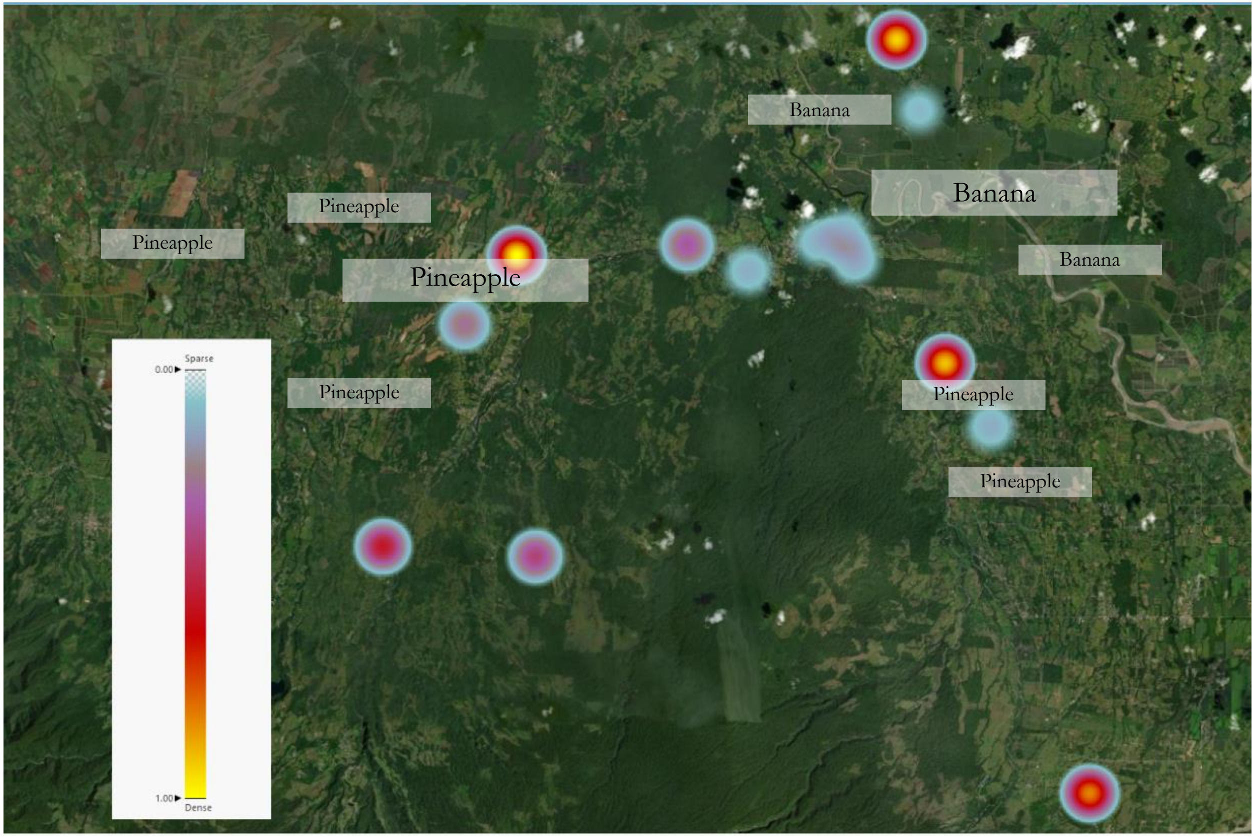

Figure S 2. Heat density map of mean total OCPs

CHAPTER 3: PESTICIDES AND MENARCHE AMONG PRE-PUBERTAL AND PUBERTAL-AGED GIRLS FROM AN INDUSTRIAL AGRICULTURAL REGION OF COSTA RICA

Abstract

While the secular trend in the global average age at menarche seems to have flattened, there remains substantial variation in the timing of menarche within populations. One proposed contributor to this variation is exposure to endocrine-disrupting chemicals such as pesticides. Here we explore the relationship between log-transformed pesticide exposure concentrations and the age at menarche using linear regression models and risk of menarche using Cox proportional hazard analysis among a cross-sectional sample of girls from a rural county of Costa Rica largely characterized by industrial commodity agriculture. We used silicone wristbands to capture and assess total pesticide exposures as well as exposure to total current-use pesticides (CUPs) and metabolites, total organochlorine pesticides (OCPs) and metabolites, current-use herbicides, insecticides, and fungicides, and specific individual pesticides to capture any differential associations with menarche. We find that total pesticide load and total CUPs were not related to age at menarche, but current-use fungicides and azoxystrobin were associated with earlier ages at menarche, while OCPs were associated with later menarche. No logged pesticide variables significantly predicted the hazard of menarche in the Cox proportional hazard models. This is among the first studies to assess and find relationships between menarche and fungicides, providing valuable contributions to understanding the potential varying effects of different types of pesticides on sexual maturation among pre-

pubertal and pubertal-aged girls. The findings also contribute to important conservations within environmental- and public health regarding the multifaceted connections among environments, pubertal development, and health risks.

Introduction

Across populations, biological females have exhibited a secular decline in the age at pubertal onset (Eckert-Lind et al., 2020). While this was initially indexed as earlier menarche, many researchers contend that average age at menarche has stabilized in recent decades (Eckert-Lind et al., 2020; Euling et al., 2008; Houghton et al., 2023; Mouritsen et al., 2010). There remains, however, substantial intrapopulation variation in age at menarche. Research has found that girls of minority racial and/or ethnic identities, from low-resource households and neighborhoods, who are food-insecure and rely on energy-dense processed foods, and who experience psychosocial stress and/or trauma have earlier ages at menarche when compared to the population average or control samples (Acker et al., 2023; Burris et al., 2020; Burris & Wiley, 2021; Hulanicka et al., 2001; Srikanth et al., 2023). Another factor that researchers believe is contributing to continual declines in the timing of puberty among females is exposure to endocrine-disrupting chemicals (EDCs) (Euling et al., 2008; Fudvoye et al., 2019; Meeker, 2012; Mouritsen et al., 2010; Ozen et al., 2012; Parent et al., 2003). EDCs are synthetic organic chemicals that impact the synthesis, breakdown, and receptor activity of steroid hormones including those involved in the onset and rate of puberty such as the luteinizing hormone, androgens, progestins, and oestrogen (Ford et al., 2024; Gore et al., 2015; Xu & Bo, 2022). As such, various classes of EDCs have been associated with altered pubertal timing and rates among both girls and boys. Because exposure to EDCs also varies by social and environmental circumstances, this may contribute to variation in age at menarche among vulnerable groups. Pubertal timing results from gene-by-environmental interactions operating through switch mechanisms in the hypothalamus-pituitary-gonadal axis (HPGA) (Ellis et al., 2013). Puberty begins when gonadotropin-releasing hormone (GnRH) is secreted from the hypothalamus in an unknown specific frequency and amplitude (Ford et al., 2024). This stimulates the release of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), leading to the production of estradiol and follicular luteinization among girls (Abreu & Kaiser, 2016; Ford et al., 2024). Menarche, the first regular menstruation among biological females and typically the last pubertal landmark event, is stimulated by a consistent rise in estradiol (Lacroix et al., 2023). The peak[7] in estradiol produces negative feedback on the gonotrophic axis resulting in cyclical estrogen levels and menstrual cycles (Lacroix et al., 2023).

Because pubertal timing is highly sensitive to environmental context, it varies between individuals and populations and can be used to understand variation in reproductive strategies as an evolutionary adaptive strategy using life history theory. Life history theory in evolutionary biology provides the foundation to understand the variation in the timing of life stages such as birth, childhood, sexual maturation, reproduction, and death (Said-Mohamed et al., 2018; Stearns, 1992). Life history events are characterized by metabolic tradeoffs in which limited resources are allocated toward growth, reproduction, parental investment, maintenance, and survival (Said-Mohamed et al., 2018). Menarche is a life history event marking the change in energy allocation from somatic maintenance and other developmental processes to reproductive efforts. The timing of menarche has been shown to be influenced by energy

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[7] There is not a specific level of estradiol that universally stimulates menarche for all individuals. It is highly variable.

availability and stress (Rogers, 2018), and as such, it is often analyzed to understand connections between environmental context and reproductive strategies (i.e., life history tradeoffs, developmental adaptation). Earlier menarche can reduce or even halt the development and maintenance of metabolic, musculoskeletal, neurological, and immune systems, leading to increased risk for associated diseases. For example, early menarche has been connected to adolescent and adult-onset depression, behavioral problems, early sexual activity, growth stunting, obesity, type-2 diabetes, asthma, cardiovascular disease, and cancer (Cheng et al., 2020; Ibitoye et al., 2017; Jasienska et al., 2017; Werneck et al., 2018).

Many pesticides, which are categorized by their target organisms and include insecticides (and nematicides), herbicides, and fungicides, have endocrine-disrupting properties related to their mode of action (Gore et al., 2015; Marcu et al., 2023). For example, endocrine-disrupting pesticides can interact directly with nuclear receptors including those involved in hormonal pathways (e.g., estrogen-, androgen-, thyroid receptors). The effects of agrochemicals on steroid hormones involved in reproduction varies. For example, some are highly estrogenic while others target androgenic receptors (Arena et al., 2018; Mnif et al., 2011; Warner et al., 2020). Endocrine disruption is one proposed pathway between pesticide exposure and various diseases including hormonal disorders, infecundity, birth defects, and cancer (Pathak et al., 2022). As a result, pesticides are considered a *contaminant of emerging concern* by the U.S. Environmental Protection Agency and environmental health researchers (Marcu et al., 2023). While much of pesticide exposure and health research has focused on adults, particularly those exposed through occupational means and pregnant women, it is important to understand the physiological impacts of pesticide exposure among children during critical periods of development like puberty as alternations in maturation can have long-term effects. Plus, studies consistently show that children and adolescents have higher detected exposures to pesticides compared to adults (Brühl et al., 2023; Fuhrimann et al., 2022; Veludo et al., 2024) and show relatively more health consequences (Pathak et al., 2022). Children are more likely to have higher exposure levels due to the higher ratio of ingested items (e.g., food, air) per body size, and shorter statures combined with more time spent closer to, or on, the ground/floors where some chemicals accumulate (Mastorci et al., 2021).

Investigations of the connections between pesticide exposure and pubertal timing/rate have been inconclusive and show differential outcomes based on the timing of exposure and sex likely due to variation in mechanisms of action across different types of pesticides. Some have found exposure to insecticides, specifically OCPs, organophosphates, and pyrethroids, during adolescence is associated with later sexual maturation and menarche, while prenatal exposure to a pesticides more generally has been connected to earlier pubertal development (Attfield et al., 2019; Bapayeva et al., 2016, 2018; Castiello et al., 2023; Castiello & Freire, 2021; Uldbjerg et al., 2022; Wohlfahrt-Veje et al., 2012, 2016). Other evaluations show greater exposure to organophosphates and fungicides may predict earlier pubertal development among girls but later maturation in boys (Castiello et al., 2023).

Nearly all previous investigations of pesticides and pubertal development have focused on pesticide classes, particularly organochlorine pesticides (OCPs), ignoring the potential cocktail effects of simultaneous exposure to different types. The physiological impacts of EDCs may result from interactions and have inverse, balancing, or exacerbating effects. Thus, it is important to understand how *total pesticide exposure load* may contribute to variation in pubertal timing and rate, particularly among populations most at risk for exposure and early menarche due to social-ecological factors. The exposome is a valuable conceptual framework for investigating these connections as it stresses the importance of considering all human environmental exposures throughout the life course in providing a holistic understanding of the determinants of exposure-related disease risk and outcomes (Siroux et al., 2016; Wild, 2012).

Girls from rural agricultural communities may be especially vulnerable to endocrine disruption as the result of exposure to pesticides in the environment (e.g., consumption of locally produced foods, atmospheric drift, water contamination) and face a greater risk of altered trajectories of pubertal maturation. In this analysis, we explore the connections between pesticide exposure and the timing of menarche among a subsample of girls aged 8 to 16 years living in Sarapiquí, Costa Rica. Sarapiquí is a rural agricultural region characterized by large-scale monocultures of primarily banana and pineapple crops grown for exportation by multinational agribusinesses. We evaluate exposure to the sum of detected current-use pesticides (CUPs), organochlorine pesticides (OCPs), and total pesticide load (TPL: sum of CUPs and OCPs) among girls living in different social-ecological contexts (SECs: rural agricultural, rural non-agricultural, urban-peri urban, and mosaic landscapes with both forest and agriculture). We also assess specific pesticide types and individual pesticides and their associations with menarche. To estimate pesticide exposure, we used silicone wristbands–a novel, non-invasive method of measuring individual passive exposure to organic chemicals (O’Connell et al., 2014). The wristbands have been validated as a credible method for estimating exposure through respiration and dermal contact but are less reliable for estimating exposure through ingestion (Venier et al., 2018).

Methods

This assessment uses a subsample from a larger research initiative aimed at understanding the associations between living in different types of rural environments characterized by industrial agriculture and reproductive maturation. Here we specifically evaluate the connections between pesticide exposure and age at menarche.

Recruitment for the study utilized local schools, community organizations, and word-of-mouth. Researchers provided a brief overview of the study and consent/assent forms to girls and parents if present. Snowball recruiting was also used; participants were asked to recommend additional eligible girls. Since the study was designed to assess pesticide exposure and reproductive maturation, girls had to be at least eight years of age and preferably under 17 years. All participants provided informed consent from a parent or guardian along with informed assent. We aimed to sample evenly across different landscapes to capture predicted variation in pesticide exposure between girls living in agricultural and non-agricultural communities. However, due to the dominance of agriculture throughout the county and low population density in rural areas, the sample encompasses more participants living near agriculture than those from the other contexts, which for this analysis were categorized as rural nonagricultural, urban/peri-urban, and mosaic (forest-agriculture mix). For more information on the variation in pesticide exposure across these different social-ecological contexts (SECs), refer to Howe et al., *forthcoming*).

A survey was used to collect demographic and household information including birthdate, nationality of girls and their caretakers, household size and composition, monthly household income, household members' occupation(s) including type of work and workplace, how long the girls had lived in their current location, and whether past residencies were near to agricultural fields. Household members' occupations were used to calculate the number of household members working for local agricultural plantations. Nationality was coded as Nicaraguan or Costa Rican, and household composition was divided into single-caretaker and multi-caretaker households. Because the distribution of income was heavily skewed to the left, median monthly household income was used to dichotomize the sample into households above or below the median household income (₡300,000, which translated to USD $450 at the time of data collection (March-June 2022)). Current residency and distances to agriculture and forest measured using Google Earth were used to categorize participants by SEC[2] including rural agricultural, rural nonagricultural (forest, pasture, or both), urban/peri-urban, and mosaic (agriculture + forest). The survey also incorporated questions regarding whether participants had experienced menarche, the date of menarche, and maternal age at menarche. The participants' birth date was subtracted from their date of menarche to calculate the exact age at menarche. Girls were categorized into pre- and post-menarche groups based on whether they had experienced menarche at the time of the survey, and post-menarcheal girls were further dichotomized by whether they had experienced menarche before or after the median age at menarche (12 years).

Anthropometric data included weight, height, and triceps skinfolds. Weight and height were used to calculate BMI. The World Health Organization (WHO) growth reference data for children and adolescents 5-19 years was used to calculate z-scores for height for age (HAZ) and BMI for age (BMI-Z) (De Onis et al., 2007) and categorize the sample into nutritional status groups to calculate the number of girls with BMI-Z considered overweight (1 SD > = 2 SD) or obese (> 2 SD).

Black silicone wristbands were purchased from 24hourswristbands.com (Houston, TX) and deployed to capture exposure to CUPs and OCPs. The OCPs under investigation are prohibited for agricultural use in Costa Rica. However, they may be applied for public health purposes to reduce vector-borne diseases, and they persist in the environment. Persistence duration is not known with any certainty, but we have evidence of environmental accumulation of pesticides thought to have been applied decades ago (e.g., pre-1970s before the U.S. banned DDT; pre-2001 before the Stockholm Convention treaty)(Chaudhari et al., 2023; USGS, 2000)). Before deployment, the wristbands were cleaned and individually wrapped in aluminum foil by the Venier Environmental Chemistry Laboratory at Indiana University. For a complete description of the pre-deployment methods, see Romanak et al., 2019 and Wang et al., 2020. After piloting the wristbands among youth in the study region, we used rivets to make the wristbands into smaller sizes to ensure a secure fit. At the initial household meeting, participants were given a conditioned silicone wristband and instructed to wear it consistently for at least three days including while bathing, sleeping, and washing hands. At the collection meeting, the participants removed the wristbands and placed them in the original aluminum foil wrapping. Girls wore the wristbands for an average of 108 hours, or 4.5 days (sd = 22.3). The foil-wrapped wristbands were then placed in individual plastic bags, labeled, and immediately transported and stored in –20 C freezers until extraction.

Laboratory procedures took place in the Venier Environmental Chemistry Lab at Indiana University. While the whole sample for the larger project consisted of 192 individuals, we were only able to analyze a subset (n = 54) due to budget and time constraints. The additional 137 wristbands will be analyzed in the future to more fully explore the impacts on pubertal timing among the full sample. The subsample wristbands were selected based on SEC, age, and household to ensure all SECs were represented, a wide age range, and samples were not from the same household.

We extracted and analyzed the participant wristbands according to the protocol published by Essandoh et al. (n.d.). We additionally analyzed six field blanks which were used as controls for quality analyses and corrections (see Essandoh et al., n.d. for the full protocol). We tested for 42 CUPs and 16 CUP metabolites and 15 OCPs and 6 OCP metabolites. The data were converted to nanogram/gram concentrations according to the wristband sample weights. All detected concentrations of CUPs and OCPs, including their metabolites, were summed to calculate total concentrations for CUPs and total OCPs. Total CUPs and total OCPs were summed to provide a quantity for the total pesticide load (TPL). The current-use pesticides that were detected at ≥25% detection frequencies were categorized into herbicides, insecticides, and fungicides and their concentrations summed to create the variables CUP herbicides, CUP insecticides, and CUP fungicides.

Data Analysis

Data analysis was conducted using Stata/SE 17. Power analysis indicated 98.3% for a sample size of 54 and a multiple linear regression with three covariates and an R^2 of 0.3. Summary statistics were calculated for sample demographic and biological characteristics and pesticide exposure. Total CUPs, total OCPs, and TPL were assessed as continuous variables and quartiles. Individual pesticides and the grouped pesticide variables (herbicides and insecticides since only one pesticide was classified as a fungicide) were assessed as continuous variables.

The log for each pesticide variable was calculated and used for all hypothesis testing to achieve normality of the distribution. Among girls who had reached menarche, linear regression assessed associations between age at menarche and log-transformed pesticide concentrations, household characteristics, and anthropometrics while adjusting for age. When using categorical variables as predictor (independent) variables in regression analyses, the median was used as the base comparison variable. For example, when using household size as a predictor of age at menarche, the household size of four was used as the base variable. When using quantiles in the regression analyses, the lowest quantile was used as the base comparison variable to test the hypothesis that higher exposure concentrations would contribute to variation in age or risk of menarche. Covariates that predicted age at menarche and were not significantly confounded were included in multivariate analyses. Finally, we used Cox proportional hazard (PH) analysis to evaluate the hazard ratio for experiencing menarche at all ages and by age 12 while adjusting for log-transformed pesticide exposure and censoring for girls who had not reached menarche to incorporate the entire sample. We adjusted for variables correlated with age at menarche in the multivariate regression models. Failure was determined by whether the individual had reached menarche in the general hazard analysis and whether they had menarche by age 12y in the analysis predicting menarche <12y.

Results

Sample Description

Table 1 contains summary descriptions of the total sample characteristics and stratified by menarche groups (pre-post, <12y≥). The mean age of the participants was 12.6 years. Around 44% lived in rural agricultural communities and 44% had at least one household member who worked for a large-scale agribusiness. Approximately 57% (n = 31) of girls had experienced menarche and 52% had reached menarche before age 12. Among those who had reached menarche, the mean age of menarche was 11.7 years (SD = 1.1, median = 11.9) and ranged from 9.1 to 14.1 years.

Table 1. Sample Characteristics and Menarche

Sample characteristic	Total Sample %	age at menarche mean (SD)(y)	Regress B	Pre-Menarche % (n=31)	Post-menarche % (n=23)	Logistic OR (n=54)	Menarche <12 y % *(girls 12y+,* n=14)	Menarche ≥12 y % *(girls 12y+,* n=15)	Logistic OR *(girls 12y+, n=29)*
Social-Ecological Context (SEC)									
$^+$Rural Agricultural	44.4%	11.7 (1.2)	--	25.0%	75.0%	--	55.6%	44.4%	--
Rural Nonagricultural	20.4%	11.7 (1.4)	-0.0	63.6%	36.4%	0.0	50.0%	50.0%	0.8
Urban-Peri Urban	25.9%	11.9 (0.6)	0.3	50.0%	50.0%	0.3	50.0%	71.4%	0.3
Mosaic Agriculture-Forest	9.3%	11.0 (0.3)	-0.7	60.0%	40.0%	0.0	100.0%	0.0%	
Household Size (2-7)									
2-3	27.8%	11.5 (1.0)	0.2	46.7%	53.3%	0.3	50.0%	50.0%	0.3
$^+$4	29.6%	11.4 (1.0)	--	37.5%	62.5%	--	75.0%	25.0%	--
5	24.1%	11.6 (1.2)	0.3	38.5%	61.5%	0.2	50.0%	50.0%	0.3
6-7	18.5%	12.8 (0.7)	1.4*	50.0%	50.0%	0.1	0.0%	100.0%	1.0
Nationality									
$^+$Costa Rican	90.7%	11.7 (1.1)	--	44.9%	55.1%	--	48.0%	52.0%	--
Nicaraguan	7.4%	11.6 (0.7)	-0.1	25.0%	75.0%	3.9	66.7%	33.3%	2.2
Caretaker Nationality									
$^+$Costa Rican	63.0%	11.8	--	44.1%	55.9%	--	47.1%	52.9%	--

		(1.0)							
Nicaraguan	37.0%	11.6 (1.3)	-0.2	40.0%	60.0%	1.1	50.0%	50.0%	1.1
Number of Caretakers									
+Multiple	69.8%	11.8 (1.2)	--	45.9%	54.1%	--	47.4%	52.6%	--
Single	30.2%	11.5 (1.0)	-0.3	37.5%	62.5%	3.3	55.6%	44.4%	1.4
Farmwork									
+Non-farm Working Member	51.9%	11.7 (1.2)	--	53.3%	46.7%	--	50.0%	50.0%	--
Farm Working Member	48.2%	11.7 (1.0)	0.0	29.2%	70.8%	3.0	46.7%	53.3%	0.9
Income									
+< ₡300,000 ($450)	53.5%	11.3 (1.1)	--	43.5%	56.5%	--	55%	35.7%	--
+≥ ₡300,000 ($450)	46.5%	12.1 (1.0)	0.8	30.0%	70.0%	0.6	45%	64.3%	0.5

Alpha <0.05, *p <0.05, **p<0.01, ***p<0.001 ;
n for groups : pre-menarche = 23 ; post-menarche = 23 ; menarche <12 y = 14, menarche ≥12 y = 15
+Base comparison variables: rural agricultural SEC, household size of 4, Costa Rican nationality of girls and caretakers, multiple caretakers, non-farm working household member, income <₡300,000
Linear regression predicting age at menarche was only conducted among the sample that had reached menarche. Logistic regression predicting menarche (y/n) controlled for age
Logistic regression predicting menarche <12y was conducted among girls aged 12y+.

The summary statistics for the anthropometric data and the percentage of girls who were post-menarche for each age group are presented in Supplementary Table 1 (i.e., s Table 1). In total, 14.8% had BMI-Z scores considered overweight and 3.7% had BMI-Z indicative of obesity. There was a substantial increase in weight, BMI, and triceps at age 12, which paralleled with the median age at menarche.

Table 2 provides the detection frequencies and mean concentrations for CUPs, OCPs, TPL, and the individual pesticides that were detected at 95%+ frequency for the total subsample as well as stratified by menarche groups. For a list of pesticides detected (≥ 25%) including detection frequencies and concentrations see Howe et al., *forthcoming.* CUPs were detected at relatively higher concentrations and frequencies compared to OCPs.

Table 2. Summary of Pesticide Detection Frequencies and Concentrations in Silicone Wristbands (ng/g)

	Total Sample		Pre-Menarche		Post-Menarche		Menarche < 12 y		Menarche ≥ 12 y	
Pesticide	Type	Mean (SD)	DF %	Mean (SD)	DF%	Mean (SD)	DF%	Mean (SD)	DF %	Mean (SD)
Total CUPs		127.9 (181.3)	100.0%	132.6 (176.9)	100.0%	124.4 (33.7)	100.0%	77.3 (52.3)	100.0%	139.7 (222.8)
CUP *herbicides*		20.9 (39.3)	100.0%	22.8 (45.0)	100.0%	19.6 (35.2)	100.0%	12.7 (15.7)	100.0%	27.7 (47.8)
CUP *insecticides*		98.2 (169.6)	100.0%	97.5 (151.5)	100.0%	98.8 (184.4)	100.0%	55.1 (43.2)	100.0%	108.7 (219.0)
CUP *fungicides*		6.6 (16.3)	100.0%	9.5 (20.7)	100.0%	4.6 (12.6)	100.0%	7.8 (18.5)	100.0%	2.2 (2.4)
CUPs >95% DF										
Ametryn^{b}	Herb	1.6 (1.9)	100.0%	1.0 (1.5)	100.0%	1.9 (2.0)	100.0%	1.3 (1.7)	100.0%	2.3 (2.0)
Diuron^{b,c}	Herb	13.9 (35.0)	100.0%	15.1 (39.4)	100.0%	13.0 (32.0)	100.0%	8.9 (11.9)	100.0%	18.1 (44.8)
Ethoprophos^{b,c}	Ins	21.8 (61.8)	100.0%	33.0 (92.0)	100.0%	13.4 (19.1)	100.0%	8.6 (9.1)	100.0%	17.4 (25.3)
Diazinon^{b,c}	Ins	69.2 (145.7)	100.0%	53.9 (103.3)	100.0%	80.5 (171.4)	100.0%	38.4 (32.1)	100.0%	88.9 (200.2)
Fipronil^{b,c}	Ins	4.8 (13.7)	95.7%	6.8 (14.0)	96.8%	3.3 (13.5)	92.9%	6.4 (20.5)	100.0%	0.9 (1.6)
Fipronil Desulfinyl	Metab, Ins	0.2 (0.63)	100.0%	0.4 (0.9)	100.0%	0.1 (0.3)	100.0%	0.2 (0.4)	100.0%	0.1 (0.1)
Fipronil sulfone	Metab, Ins	1.4 (2.27)	95.7%	2.2 (3.0)	100.0%	0.8 (1.3)	100.0%	1.1 (1.9)	100.0%	0.5 (0.4)
Azoxystrobin	Fung	3.8 (13.7)	91.3%	5.1 (16.9)	100.0%	3.0 (11.2)	100.0%	5.8 (16.5)	100.0%	0.7 (0.8)
Total OCPs		25.7 (37.6)	100.0%	20.5 (32.8)	100.0%	29.9 (41.1)	100.0%	37.1 (54.4)	100.0%	18.8 (10.6)
OCPs >95% DF										
B-HCH^{a,b,c}	Ins	0.1 (0.2)	100.0%	0.01 (0.0)	100.0%	0.1 (0.3)	100.0%	0.02 (0.0)	100.0%	0.2 (0.4)
p,p'- DDT^{a,b,c}	Ins	17.5 (34.2)	100.0%	16.1 (32.8)	100.0%	18.6 (35.9)	100.0%	20.9 (45.3)	100.0%	11.0 (9.5)
Total Pesticide Load (TPL)		157.3 (192.9)	100.0%	153.1 (181.0)	100.0%	160.5 (205.0)	100.0%	116.3 (85.9)	100.0%	167.7 (228.1)

n for groups : pre-menarche = 23 ; post-menarche : CUPs = 31, OCPs = 29 ; Menarche < 12 y : CUPs = 14, OCPs = 13 ; Menarche ≥ 12 y : CUPs = 15, OCPs = 14

CUPs = Current-use Pesticides; OCPs = Organochlorine Pesticides ; DF = detection frequency

[a] banned by the Stockholm Convention (UN, n.d.); [b] banned or not approved by the European Union (PAN International, 2022); [c]

banned by one or more countries according to the PAN International Consolidated List of Banned Pesticides (PAN International, 2022)
B-HCH = B-Hexachlorocyclohexane ; p,p'-DDT = 4,4'-Dichlorodiphenyltrichloroethane
Ins = insecticide; Herb = herbicide; Fung = fungicide; Metab = metabolite

Determinants of Age at Menarche

Unadjusted linear regression (post-menarche girls)

Among girls who reached menarche, age at menarche was not associated with log-transformed- total CUPs, CUP *herbicides*, CUP *insecticides*, total OCPs (as a continuous variable), individual OCPs, or TPL. The logged concentrations of CUP *fungicides* and the fungicide azoxystrobin, specifically, were negatively correlated with age at menarche ($r^2 = 0.14$, $p = 0.034$; $r^2 = 0.20$, $p = 0.011$) (Figure 1). All quartiles (Q) greater than 1 for the logged OCP concentrations were positively related to age at menarche compared to Q1 (Table 3, Figure 2). Mean ages at menarche for each OCP quartile were: Q1 = 10.6, Q2 = 11.9, Q3 = 12.2, and Q4 = 11.7.

Among the household characteristics, only the household size of 6-7 individuals significantly predicted later ages at menarche compared to households of 4 (B = 1.4, p = 0.018). Other household factors (income, nationality, caretaker nationality, number of caretakers, household members working in industrial agriculture, living near agriculture in the past) were not associated with age at menarche. Similarly, no anthropometric variables (weight, height, BMI, triceps, BMI-Z, HAZ, overweight, obese) were significantly associated with age at menarche.

Adjusted linear regression (post-menarche girls)

Adjusting for household size, linear regression results indicated that CUP *fungicides*, azoxystrobin, and OCPs Q3 and Q4 were significantly associated with age at menarche (Table 3). CUP *fungicides* and azoxystrobin predicted earlier ages and OCPs Q3 and Q4 predicted later ages at menarche. Household size of 6-7 was not, however, significant associated with age at menarche in the multivariate models.

Table 3. Results from Linear Regression Analysis Predicting Age at Menarche

	Unadjusted		Adjusted[a]	
Log-transformed independent variables	B	95% CI	B	95% CI
CUP *fungicides*	-0.4*	-0.7, -0.03	-0.5**	-0.8, -0.1
Azoxystrobin	-0.4*	-0.6, -0.1	-0.4**	-0.7, -0.2
+OCPs Q1	--	--	--	--
OCPs Q2	1.3*	0.05, 2.5	1.1	-0.1, 2.4
OCPs Q3	1.6**	0.5, 2.7	1.6**	0.5, 2.8
OCPs Q4	1.1*	0.05, 2.2	1.2*	0.1, 2.3

[a] adjusted for household size
Alpha <0.05, *p <0.05, **p<0.01, ***p<0.001
B = coefficient ; CUPs = current-use pesticides, OCPs = organochlorine pesticide, Q = quartile
+Base comparison: OCP Q1, households of 4

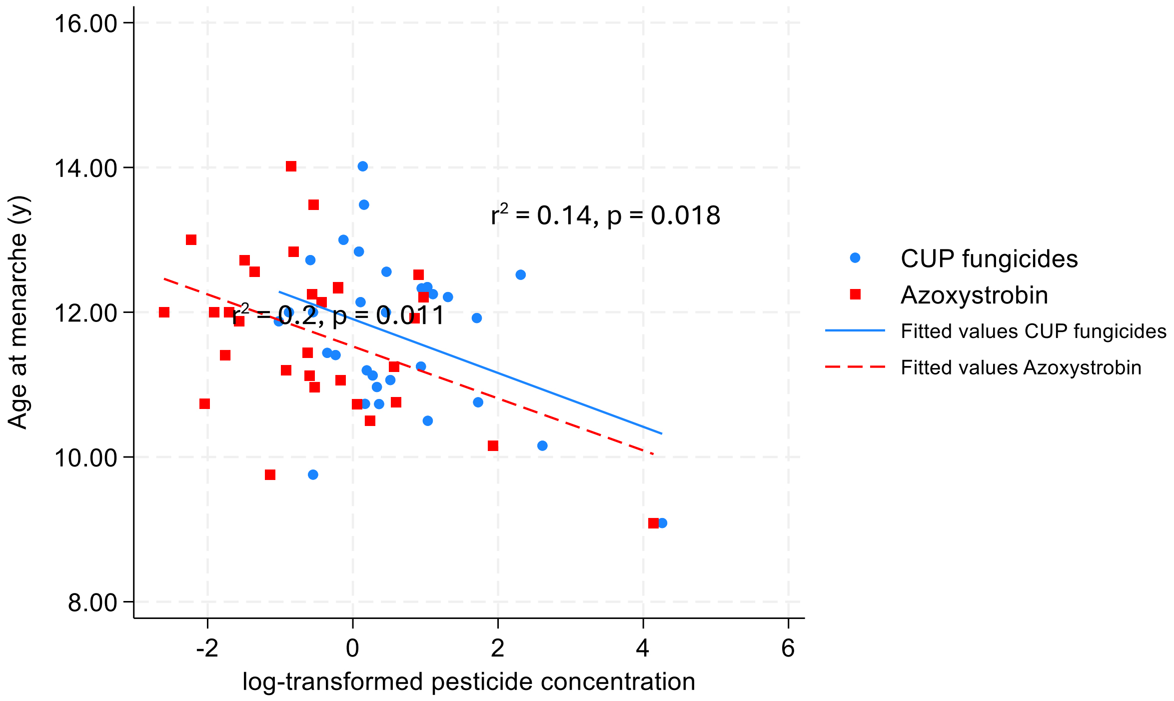

Figure 1. scatterplot showing significant correlations between age at menarche and logged CUP fungicides concentrations and age at menarche and logged azoxystrobin concentrations. Logged CUP fungicides concentrations are represented with blue circles, and the solid blue line represents the fitted values for CUP fungicides. Red squares represent logged concentrations of azoxystrobin, and the dashed red line represents the fitted values for azoxystrobin. Age at menarche in years is on the y axis.

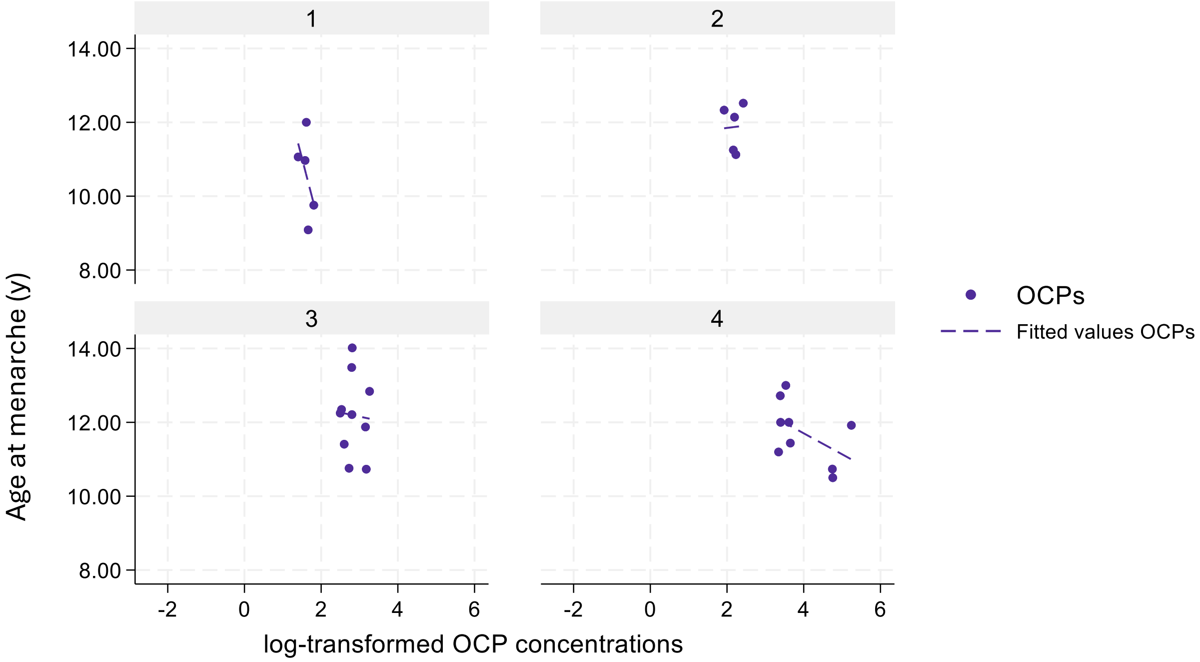

Figure 2. scatterplot showing correlations between age at menarche and log-transformed OCP concentrations. Logged OCP concentrations are represented by purple circles, and the fitted values are represented by a purple dashed line. Age at menarche in years is on the y axis.

Determinants of Menarche Hazard

No pesticide variables were associated with the hazard of menarche in the univariate Cox PH analyses using log-transformed CUP fungicides, azoxystrobin, and OCP quartiles. Additionally, household size was not significantly predictive of the hazard of menarche.

No pesticide variables predicted the risk of early menarche (<12 yrs) (among girls 12+y) in the Cox PH models including those that were significantly correlated with age at menarche. We also did not find any significant relationships between household characteristics and the hazard of menarche by age 12 in the Cox PH analyses.

Discussion

Age at menarche

There is no publicly available data on the national average or median age at menarche (or any pubertal marker) for contemporary girls in Costa Rica, making it difficult to compare our sample's age at menarche to the larger population. A recent study among 160 female students attending the University of Costa Rica found a mean age at menarche of around 12.4 y (González-Salazar et al., 2023), which is higher than our mean of 11.7 y. In a study in Sarapiquí in 2014-2016, around 35% of participants (age 25-60 years) reported menarche before age 12, which is a lower prevalence compared to our sample (52%)(del Rocío Sevilla Hernández, 2020). Therefore, our data suggests potential earlier menarche among contemporary girls living in Sarapiquí – an underdeveloped rural agricultural region with a high prevalence of poverty. Considering the samples of the other investigations, this does not come as a surprise. It is likely that individuals attending the university are of a higher socioeconomic status than the girls from our Sarapiquí sample. Furthermore, the sample from González-Salazar et al. includes women from multiple generations and because of the secular trend in age at menarche it is expected that women of older ages had a later age at menarche compared to the girls in our sample. However, since we cannot compare to the whole population, we can't say whether the lower age at menarche is unique to Sarapiquí and/or rural areas or represents a reduction in the age at menarche in younger generations in Costa Rica more generally.

Pesticides as determinants of age at menarche

Among this sample, we did not find associations between menarche and logged total pesticide exposure load or total exposure to CUPs. We did find that CUP *fungicides* and OCPs were associated with age at menarche in linear regression models. More specifically, CUP *fungicides* and the fungicide azoxystrobin, specifically, were correlated with lower ages at menarche including when adjusting for household size. OCPs quartiles 2, 3, and 4 (compared to quartile (Q)1) were associated with later ages at menarche, and Q2 and Q4 remained significantly correlated with later menarche when adjusting for household size. Thus, in this case study, it appears that different types of pesticides may have inverse associations with menarche.

The opposing directions of the relationship with age at menarche between fungicides and OCP insecticides are interesting and propose that different types of pesticides may have contrasting endocrinological or metabolic effects. Furthermore, our findings may help explain the inconclusive and sometimes opposing results of previous assessments of the relationship between menarche and pesticides, especially those that focused on specific pesticides or classes of pesticides (e.g., OCPs) independently.

We did not find any associations between pesticides and the odds of reaching menarche in general as well as before the median age of 12 years. It may be that pesticides, in this sample, contribute more to the variation in menarche risk among girls who reach menarche later than the median, perhaps due to physiological and/or energetic differences. For example, older girls may be closer to completing musculoskeletal growth and/or have more adipose tissue (including breasts) due to hormonal and metabolic changes associated with age and growth—both of which may allow energy to be available for reproductive efforts such as menstruation. In addition, many pesticides are fat-soluble and bioaccumulate (Araya et al., 2016; Pironti et al., 2021). Having more fat to store EDCs may contribute to their biological effects.

Fungicides

For the total sample, CUP *fungicides* correlated with earlier ages at menarche including when controlling for household size. However, they were not predictive of menarche before age 12. We are unaware of previous investigations that have assessed the relationship between fungicides (specifically) and menarche. We know of only one study that has explored the relationship between fungicide exposure (independently) and puberty, more generally, among humans. The aforementioned investigation evaluated ETU a biomarker of exposure to EBDC fungicides (but that is also used in plastics, rubbers, paper whitening, pharmaceutical compounds, dry cleaning, and photography) and pubertal development finding that girls with exposure levels higher than the 75th percentile had higher odds of overall pubertal development and breast development (Castiello et al., 2023), but they did not evaluate menarche.

While there is an obvious gap in our knowledge of the contributions of fungicides and the onset of menstruation, animal studies have documented endocrinological impacts of specific fungicides. For example, the dithiocarbonate fungicides mancozeb and vinclozolin as well as various triazole fungicides (e.g., tebuconazole) have been shown to inhibit androgen and imidazole fungicides seem to suppress aromatase (the enzyme that converts androgens to estrogens) activity among rats (Lv et al., 2017; Monosson et al., 1999; Skalny et al., 2021). These effects can lead to an accumulation of androgens and potentially delay or prolong pubertal development among girls such as the onset of menarche (Fukami, 2020). While not a pesticide, the antifungal drug ketoconazole was shown to delay GnRH section among rats exposed before puberty subsequently delaying pubertal onset (Franssen et al., 2023).

Azoxystrobin

We found the fungicide azoxystrobin, in particular, associated with age at menarche in the unadjusted and adjusted linear regression models. Azoxystrobin is a broad-spectrum fungicide heavily used globally for a variety of crop commodities (Seltenrich, 2022). It is among the pesticides most regularly detected at levels above the environmental quality standard in surface waters, and it is also found in dust and resistant varieties of mold within homes (W. Gao et al., 2022; Pironti et al., 2021; Seltenrich, 2022). Because of its various properties, it is classified as a nitrile, strobilurin, aryloxypyrimidine, enoate ester, enol ether, methyl ester, and methoxyacrylate antifungal. Azoxystrobin is considered to have low acute and chronic toxicity to humans (WHO, 2019) although there have been very few investigations among human samples. In animal studies, azoxystrobin is associated with reproductive health consequences. As such, it has been recommended by NIH environmental health researchers "as one of the 36 chemicals to prioritize for biomonitoring" (Seltenrich, 2022).

Azoxystrobin has organic nitriles that decompose into toxic cyanide and bind to mitochondrial cytochrome. This blocks the transfer of electrons between cytochrome b & cytochrome c1 in the mitochondrial electron transport chain (Toxin and Toxin Target Database (T3DB, n.d.)). As a result, azoxystrobin ultimately prevents the production of ATP and causes oxidative stress (W. Gao et al., 2022; T3DB, n.d.).

There are no investigations to our knowledge of the impacts of azoxystrobin on pubertal development among humans. However, animal studies show connections between long-term exposure to azoxystrobin and delays in sexual development, growth reduction, embryonic toxicity, and endocrine disruption including reduced testosterone, increased estradiol, and antagonistic effects on thyroid hormone receptor B and glucocorticoid receptor in female zebrafish, and weight loss in mice (Cao et al., 2019; A. H. Gao et al., 2014; Seltenrich, 2022; Yang et al., 2021). Perhaps a reason for the correlation with earlier menarche documented among our sample, azoxystrobin's toxic impacts have been found to impair oocyte maturation in mice (Gao et al., 2022). Using life history theory, we might posit that a reduction in oocyte vitality may induce earlier menarche and ovulation in an effort to improve the odds of reproductive success. This suggestion is further supported by an absence of association between azoxystrobin and other variables such as age, SEC, household size, and anthropometrics inferring that social and nutritional characteristics are not mediating the relationship between azoxystrobin and age at menarche in this sample.

OCPs

Total OCPs quartiles positively correlated with later ages at menarche. OCPs are organochlorine insecticides that are no longer permitted for agricultural purposes but are highly persistent in the environment (Pattnaik et al., 2020). In our sample, the primary OCPs detected were B-HCH and p,p'DDT. DDT in Costa Rica is allowed and recommended for use within public health initiatives to combat malaria.

OCPs, in general, are considered to be endocrine disrupting. Many interact with estrogen and progesterone receptors and subsequently inhibit estradiol and progesterone activity (Bapayeva et al., 2018; Mnif et al., 2011). Others have been found to bind to androgen receptors and associate with estrogen stimulation (Bapayeva et al., 2018; Mnif et al., 2011). Furthermore, different studies find opposing associations between hormone levels and detection levels of OCPs leaving our understanding of their impacts on living humans inconclusive (Bapayeva et al., 2018; Mnif et al., 2011; Pironti et al., 2021). Therefore, the endocrinological effects of OCPs vary and the exposure to different OCPs may counteract, balance, or exacerbate their biological impacts.

Most previous investigations of OCPs and pubertal development do not assess total OCP exposure load. Rather they focus on specific OCPs. For example, some studies have found connections between the OCPs DDT and HCB and later menarche (Attfield et al., 2019; West et al., 2021) and 24- and 25-DCP and earlier menarche (Udjer et al., 2022; Harley et al., 2019). Our total OCPs included DDT and HCB but not 24/25-DCP (for a full list of the pesticides detected, see Howe et al., *forthcoming*). Thus, our findings are in line with those that have found connections between OCPs and later age at menarche. However, it is important to note there may be other factors, either environmental or physiological, that contribute to the variation in menarche risk associated with OCP exposure. In this sample, household size seems to be a potential candidate as OCPs Q4 became more strongly associated with later ages at menarche when adjusting for household size in the linear regression models. Thus, household may mediate, at least partially, the relationship between OCPs and later menarche/lower risk among this sample. We can't explain this relationship, but we can speculate–it may be related to resource allocation within the household, where larger households may have less resources per individual. However, household size was not significantly related to total household income nor anthropometrics. Thus, there does not seem to be a socioeconomic/energetic driver for the relationship between household size and menarche. Perhaps larger households infer more exposure to OCPs from more individuals entering and exiting the home. Yet, OCPs did not significantly vary between household size groups. Household size was, though, associated with exposure to CUPs and total pesticide load. Girls from households with 6+ members had the highest mean total CUPs and TPL. Therefore, the connection between household size, age at menarche, and OCPs may be, at least in part, related to higher overall exposure.

Variables that are typically related to age at menarche, such as anthropometric measures, maternal age at menarche, and income (Deardorff et al., 2014; Srikanth et al., 2023; Yermachenko & Dvornyk, 2014), were not significant determinants of age at menarche or risk of menarche before age 12 in this sample. We cannot fully explain this finding. The sample size is small and may not adequately represent population variation. Relatedly, both statistical and ethnographic observations find a lack of variation in socioeconomic factors, diet, and lived experiences among the subsample, full sample, and Sarapiquí residents more largely (Howe et al., *forthcoming*). For example, income does not widely vary among sample households, and even with some variation in income, income is not significantly related to other variables including diet, nutritional status, SEC, and pesticide exposure. This lack of variation contributes to social cohesion which may be influential for the timing of menarche. Other studies have found that the homogeneity of communities and perceived social cohesion seem to reduce the influence of socioeconomic and psychosocial variables (Acker et al., 2023; Belsky, 2010).

Since pesticide exposure was a significant predictor of age at menarche, it may be that endocrine disruption from pesticide exposure is more influential than genetics (proxied by maternal age at menarche), nutritional status, and household income. Pesticide exposure and endocrine disruption are likely to be more predominant for the girls in the sample compared to when their mothers were children and adolescents as the agricultural industry in Sarapiquí has expanded greatly over the last couple of decades (Chavarría Cruz & Castro Duarte, 2021). There is evidence of intense banana agriculture expansion on the east side of the county; and pineapple has only been a large commodity and agribusiness in Sarapiquí since the early 2000s (Chavarría Cruz & Castro Duarte, 2021; Guillén Araya, 2018). Pineapple agriculture continues to grow each year and is now a large part of the region's economy and landscape (Municipalidad de Sarapiquí, 2022; Naranjo, 2014). In a former paper, we show that pesticide exposure is connected to proximity to pineapple fields but not banana fields in this sample, and girls living near pineapple fields have higher pesticide exposure load compared to those from banana communities (Howe et al., *forthcoming*). Thus, the recent expansion and intensity of pineapple agriculture in Sarapiquí may contribute to more endocrine disruption and/or energetic effects among contemporary girls compared to their mothers.

Limitations

The data are cross-sectional, and more research is necessary using longitudinal analyses. This analysis uses a small subsample due to budget and time constraints associated with the pesticide laboratory testing and analyses. Larger and more representative samples are necessary. In addition, the age at menarche was based on recall. However, 84% of the sample knew the exact date of their first menstruation, and all remembered the year and/or their age.

Conclusion & Implications

We provide data on age at menarche, pesticide exposure, and nutritional status for a sample of girls from an understudied community–contributing to the shallow pool of published information on the residents of Sarapiquí and environmental health. This is among the first analyses to assess and show an inverse relationship between pubertal timing and exposure to current-use fungicides including specifically azoxystrobin. We did not find significant relationships between menarche and total pesticide load including when assessing total CUPs. However, higher total OCP exposure was predictive of later menarche. The study findings contribute valuable information on the differential relationships that pesticides may have with reproductive maturation and provide potential reasoning as to why studies exploring the relationships between menarche and pesticides, thus far, have been inconclusive. Furthermore, since fungicides specifically associated with earlier menarche and early menarche has been connected to increased disease risk, it may be that fungicides play a mediating role within pubertal timing and health outcomes. Further assessments of fungicides as well as total pesticide load among larger longitudinal samples are necessary to better understand their potential roles within sexual maturation and disease.

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Supplementary Materials

Table S1. Summary Statistics for Anthropometry and Menarche Stratified by Age in Years

		means (SD)						%	mean
Age (y)	n	weight (kg)	height (cm)	HAZ	BMI	BMIZ	Triceps SF (mm)	Menarche	Age at Menarche (y)
8	5	28.1 (2.0)	128.8 (3.4)	-0.8 (1.2)	17.0 (1.1)	-0.2 (1.4)	16.3 (2.6)	0%	-
9	3	30.1 (1.1)	132.3 (2.2)	-0.7 (0.7)	17.2 (0.2)	-0.4 (0.8)	15.0 (3.5)	0%	-
10	9	36.8 (9.8)	143.3 (8.3)	-0.1 (1.0)	17.7 (3.4)	0.5 (1.3)	14.6 (5.6)	11.1%	10.7
11	6	36.9 (6.5)	144.4 (6.1)	1.1 (1.3)	17.6 (1.6)	1.0 (1.0)	15.1 (3.9)	16.7%	11.0
12	7	46.0 (4.0)	151.1 (5.2)	-0.9 (0.6)	20.2 (1.9)	-0.2 (0.4)	18.4 (4.4)	85.7%	10.9 (1.3)
13	8	47.1 (8.7)	155.2 (8.1)	0.0 (0.8)	19.4 (2.9)	0.1 (1.6)	20.3 (6.7)	87.5%	11.2 (0.7)
14	8	57.4 (14.1)	161.3 (11.4)	-0.2 (0.7)	21.8 (3.2)	0.2 (0.6)	22.1 (10.1)	100.0%	12.6 (0.7)
15	3	55.7 (3.9)	157.0 (9.2)	0.2 (0.7)	22.7 (1.8)	0.2 (0.5)	24.1 (5.4)	100.0%	12.6 (0.8)
16	5	55.2 (8.1)	158.5 (2.9)	-0.1 (0.8)	22.0 (3.1)	-0.3 (0.7)	25.4 (8.4)	100.0%	11.7 (0.9)

CONCLUSION

Summary of the Work and Main Findings

This biocultural investigation compared differences in food insecurity and pesticide exposure and their relationships with nutritional status and pubertal timing among girls from different communities of Sarapiquí, Costa Rica. In Chapter 1, I assessed food insecurity, diet, nutritional status, and pubertal timing across different landscapes to evaluate spatial inequalities within the larger rural setting and their relationships with socio-political-economic activities (e.g., industrial agriculture) and geospatial-ecological variation. In Chapter 2, I compared pesticide exposure among girls from communities surrounded by monocultures to those from non-agricultural communities, testing the assumption that non-agricultural spaces are buffered from pesticide exposure due to farther distances from application sites and potential protection from forest. In Chapter 3, I evaluated the relationships between pesticide exposure and age at menarche. Unlike previous investigations of pesticides and puberty that solely focused on specific classes of current-use pesticides (CUPs) (e.g., organophosphates, pyrethroids) or only organochlorine legacy pesticides (OCPs), I implemented new questions and analyses that explored *total* pesticide exposure load (TPL), total current-use pesticides (CUPs) calculated as the sum of all CUPs detected per sample, total organochlorine pesticides (OCPs) calculated as the sum of all OCPs detected per sample, categories of CUPs including herbicides, insecticides, and fungicides, as well as individual pesticides and metabolites. This was achievable thanks to the utilization of silicone wristbands. Due to their non-invasive design, the wristbands were well accepted amongst the community and governing institutions. They were met with curiosity and a bit of fascination by youth and their guardians and had a nearly 100% return rate with only one participant having lost her wristband. Because the silicone wristbands capture exposure to a broad range of organic compounds, they allow for simultaneous testing of a variety of chemicals including different pesticide classes and compounds (Romanak et al., 2019).

While I didn't find substantial variation in age or risk of menarche based on food insecurity, social-household characteristics or nutritional status, industrial agricultural settings were significantly associated with vulnerability to food insecurity and higher exposure concentrations of both current-use- and organochlorine legacy pesticides. Lower household income contributed to food insecurity risk, and food insecurity was related to lower BMI z-scores, less fat consumption, and lower obesity prevalence. Proximity to agricultural fields, particularly pineapple plantations, was predictive of higher CUP exposure, but proximity to forest was not related to exposure among this sample. Finally, total pesticide load and the sum of CUPs were not associated with age or risk of menarche. However, the sum of CUP fungicides and azoxystrobin, specifically, were correlated with earlier menarche while higher concentrations of OCPs predicted later menarche.

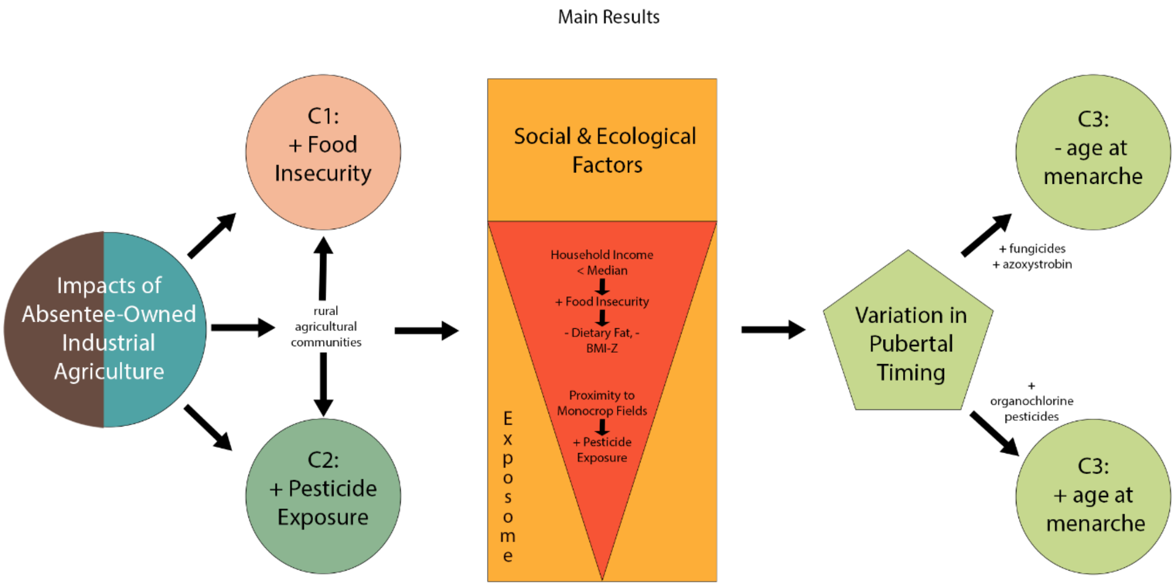

Figure 1. Diagram combining the conceptual model and research objectives, highlighting the major findings: industrial agricultural communities, driven by absentee-owned agribusinesses, were associated with higher rates of food insecurity which was connected to less fat consumption and lower BMI-z scores. Industrial agricultural communities were also associated with higher levels of pesticide exposure. Current-use fungicides were connected to earlier age at menarche and OCPs were correlated with later menarche when controlling for household size. Other variables such as household characteristics and nutritional status did not predict variation in pubertal timing.

The findings from these three case studies show the downstream impacts of the global industrial agrifood industry and the intertwined pesticide treadmill on local community members, specifically female children and adolescents, in an underdeveloped and vulnerable population of rural Costa Rica. The results paired with ethnographic data collected from 2022-2024 (which will be published in the future) argue that Sarapiquí as a geographical and political region as well as the "invisible" and visible harms induced by industrial agricultural operations in this region have been *ignored*, overlooked by the national Costa Rican government, external investors, social development initiatives, and researchers. Costa Rica is considered by the World Bank to be an upper middle-income country (The World Bank, 2024). But these classifications are based on national GDP and foreign investments in the country as a whole and do not represent the actual lived experiences of locals or the grave inequalities that exist within the country and between provinces. The province of San José, for example, where the capital lies, represents the country's primary market and the majority of economic growth and inputs (MIDEPLAN, 2017; Programa Estado Nación, 2022). In comparison to rural spaces of Costa Rica, especially those geographically, politically, and socially isolated such as Sarapiquí, San Jose is a different world, one that is ripe with opportunity and where average household incomes are double those of rural communities, and three times that of Sarapiquí households (INEC, 2023).

Not only is Sarapiquí and its residents overlooked, ignored, and left behind, but the structural violence and environmental and human health impacts are also disregarded and discounted, further obscuring the visibility of harm related to powerful multinational and absentee-owned agribusinesses. Drawing from Saxton and her research among immigrant farmworkers in California strawberry plantations, the visibility of harm depends on who is looking and is not politically neutral (Saxton, 2021). It is obvious that any existing policies enacted to protect environments and persons from hazardous agrochemicals are not sufficient, particularly among children and adolescents in this sample. If no one is looking, and if no one is enforcing policy, injustices and harm become and/or remain invisible. Therefore, it is vital for researchers to investigate these overlooked or forgotten spaces and give voice to the people who live in them. It is necessary to bring attention to the fact that injustices imposed by large agroindustry corporations are not something of history but are very real contemporary issues often influencing those at the margins of society. Through research and community engagement, we can empower communities with knowledge sharing and make visible the inequities and injustices they are exposed to, such as disproportionately higher exposures to toxic chemicals including prohibited and endocrine-disrupting pesticides and high rates of food insecurity. Furthermore, biocultural engaged anthropological research can highlight the potential biological and health outcomes associated with the embodiment of harsh, toxic environments.

Contributions

Rural Environments, Industrial Agriculture, and Community Impacts

Combining an anthropological biocultural framework with environmental endocrinology, the research contributes a biocultural understanding of the downstream effects of industrial agriculture on girls and their families in a (under)developing rural region of Costa Rica. It provides evidence for Walter Goldschmidt's argument that industrial agriculture negatively impacts social well-being and resource access of communities and exposes individuals to hazardous endocrine-disrupting agrochemicals. The dissertation shows that the presence of large-scale industrial monoculture operations is interrelated with inequality—including unequal distributions of food insecurity and pesticide exposure of which both have been connected to developmental alterations and increased risks for disease among children and adolescents (Eskandari et al., 2022; Fowler et al., 2012; Gore et al., 2015; Shimabuku et al., 2020).

By using a comparative approach and silicone wristbands, the dissertation contributes to our understanding of variation within rural spaces and moves beyond the tradition of investigating rural settings only within rural-urban comparisons (Hooks et al., 2016; Samper & González, 2020). The wristbands show differences in pesticide exposure among the girls in the sample from various communities and households. Furthermore, previous national reports of pesticide imports, registrations, and use have only provided data at the national level, and regional-specific use patterns have not been published. National level representations of pesticide use contribute to the covering or ignoring of important intra-country variation and disproportionate exposure risks. The dissertation, therefore, contributes valuable data specific to the region of Sarapiquí and pesticide exposure, which can be considered a proxy for agricultural practices and potentially environmental persistence of legacy pesticides. This information is all the more significant now, as Costa Rica and its agrochemical industry have removed registration requirements for pesticides registered for use in other countries (Mansfield et al., 2023). It does not come as such a surprise since the U.N. issued a warning to the country in 2022 after conducting an investigation of the country's pesticide use and exposure-related health impacts which put Costa Rica in national headlines as one of the highest-use countries in the world – and in contradiction to its image of the world's most eco-friendly and conservation-focused country (Alvarado-Prado et al., 2022; Vargas Castro, 2022).

While agricultural communities were the most vulnerable to food insecurity and pesticide exposure, the research did not find significant variation in income, household composition, employment in agriculture, nutritional status, or age at menarche across the different SECs. Rather, there is homogeneity in both social and biological characteristics of the sample pointing to a unique example of social and biological cohesion. Ethnographic contextual information can be applied to propose some ideas for such homogeneity including the fact that the research area is among the least developed of the country with reports stating it is some decades behind the nearest secondary rural city (León Sáenz & Arroyo Blanco, 2018). The lack of socioeconomic development has been pinned to the presence of multinational monoculture businesses as well as the marginalization of the county as it is around one hour from the nearest secondary market city and more than two hours from the country's primary metropolitan. Because of a lack of other market activities beyond agriculture, low wages are the norm resulting in minimal differences in social status and a high unemployment rate, especially among women (Municipalidad de Sarapiquí, 2022). As one interviewee stated, "donde hay monocultivos, hay salarios bajos." Therefore, the impacts of the industrial agroindustry in Sarapiquí are dispersed throughout SECs, not just among agricultural communities and those employed in the plantations. This dissertation brings attention to the unique challenges and inequities that contemporary rural agricultural communities continue to face in Costa Rica, which includes child and adolescent exposure to harmful pesticides. It highlights an area where top-down social justice and equity efforts are urgently needed.

Determinants of Pesticides

According to the findings presented in Chapter 2, factors traditionally assumed to be valid proxy measures of pesticide exposure, such as SEC, proximity to agriculture, and proximity to forest or distance from agriculture, may not be well-founded. While CUP exposure was highest near large-scale agricultural fields, especially pineapple, exposure was detected throughout the county and across all SECs with some of the second-highest concentrations documented among samples surrounded by forest or far from large-scale agriculture. Furthermore, OCP exposure was only significantly lower in urban areas and was much less variable across the sample and SECs. These findings conclude that even for rural areas with mixed landscapes, distance and forest cover may not adequately represent differences in susceptibility to pesticide exposure. This may be particularly applicable to areas with a long history of agriculture and across communities that share water sources such as in Sarapiquí. Yet, the findings also highlight the need for holistic and interdisciplinary approaches to the study of pesticide exposure as social science researchers understand that humans are not stagnant. To further understand true exposure avenues, including spaces where exposure is most probable, analyses should compare wristbands to environmental samples (e.g., water, air) taken at different commonly occupied sites such as schools, churches, markets, and other social gathering spaces.

It is important to address that pineapple agriculture in Sarapiquí has the largest association with pesticide exposure among girls in this sample, especially when compared to other commodity crop operations such as banana, yuca, palmito, and ornamental plants. In addition, the exposure concentrations from samples that lived near banana plantations were relatively low compared to samples from pineapple areas despite the fact that banana operations are reported to be use the most pesticides annually in Costa Rica (Vargas Castro, 2021). The differences may be based on variation in application methods or sampling/lab error. However, the ethnographic and qualitative data (forthcoming) align with these findings, as most of the complaints (e.g., smell, reactions) from participants and their family members were associated with the pineapple fields. Thus, the dissertation contributes important information regarding agricultural practices and sources of environmental contamination, unequal exposure to harmful pesticides, and associated risks among children, adolescents, and communities in Sarapiquí.

Determinants of Pubertal Timing

A good deal of social science research has focused on the sociocultural and economic impacts of industrial agriculture among rural communities, but human biological research is lacking. Research on health associated with industrial agriculture has focused largely on farmworkers, primarily males, and exposure to agrochemicals during pregnancy/in utero based largely on questionnaire data, cross-sectional samples, and highly limited chemicals and classes. These limitations are, of course, understood considering the invasiveness and high costs of traditional bio-sampling methods such as urine or serum. This dissertation contributes to our understanding of the relationships between rural settings engaged in industrial agriculture, pesticide exposure, and puberty, providing novel insights to the contemporary environmental determinants of human biological variation. Moreover, it is the first study, to our knowledge, to measure a broad variety of current-use pesticides and explore the connections between age at menarche and total CUPs, TPL, the sum of CUP classes, and specific pesticides. It is also the first to measure personal pesticide exposure among children and adolescents in Sarapiquí and find relationships between CUP fungicides and azoxystrobin, specifically, and age at menarche. Lastly, I found that different types of pesticides have different directions of associations with age at menarche. This may speak to the inconclusive results of previous work and shows the value in assessing individual pesticides of various classes and uses. Though, the subsample used to test these associations is small and the data are cross-sectional. Additional research among larger longitudinal samples is necessary to further test these correlations as well as to continue exploring pesticide exposure load to ensure the potential cocktail effects of exposure to various chemicals are not missed.

By providing new and exciting evidence for potential associations between pesticide exposure and pubertal development and a lack of associations between variables traditionally related to menarche among Western and urban samples, this dissertation furthers our understanding of the environmental determinants of variation in life history trajectories. It unites historical anthropological interests in the transition from juvenile to adolescence and reproductive maturation with a modern environmental component–endocrine-disrupting chemicals. Few biological anthropologists have evaluated the impact of environmental chemicals on human growth and development, and studies have primarily focused on non-pesticide pollutants or OCPs (Denham et al., 2005; Schell & Gallo, 2010; West et al., 2021). If anthropologists are to continue on the trek to understanding *what makes us human*, it is time we start considering the ever-increasing chemicals in our environments and their roles in the interrelated sociocultural and biological aspects of humanity.

This dissertation contributes to the exposome framework as a new conceptual and methodological approach to understanding how total environmental exposures throughout one’s life impacts biological and health outcomes. Chemicals make up an important part of one’s exposome, and therefore should be considered in environmental health research as well as bioanthropology. While the dissertation research is cross-sectional, it provides information as to parts of participants’ exposomes during a critical developmental period. The research adds to our understanding of not just exposure to pesticides but also natural ecologies, household characteristics, diet, and sociocultural phenomena.

It is noteworthy to underscore the absence of significant associations between age at menarche and variables that have traditionally been considered deterministic of the timing of menarche and other life history events. These include income, household characteristics (e.g., number of caretakers), maternal age at menarche, and nutritional status, all of which did not contribute to variation in age at menarche in regression models. On the one hand, the subsample used for this analysis in Chapter 3 is small and may not be representative of the larger community or population. Thus, the results should be considered cautiously. Nevertheless, the findings (or lack thereof) encourage us to reflect on long-held assumptions, which drive our research questions and methodologies, which are based largely on samples from Western populations and those with clearly established hierarchal-unequal sociocultural systems. While these assumptions are evidence-based and appropriate for similar samples and settings, they may not be appropriate among non-WEIRD (Western, Educated, Industrial, Rich, Democracies) / low-income / highly rural and homogenous populations and/or in settings with high exposure to endocrine-disrupting pesticides.

Methodological Contributions & Data

The innovative methodology utilized in this dissertation contributes to the fields of anthropology and human biology by bringing them to the fore of modern environmental and endocrine research. Most studies, until now, have relied on invasive measures such as serum, blood, urine, and saliva to analyze chemical exposure (Gore et al., 2015). The use of silicone wristbands is at the forefront of interdisciplinary research interested in environmental-toxicology, endocrinology, and health as it provides a non-invasive and affordable method for measuring individual passive chemical exposure. Merging this new method with anthropology makes sense, as anthropologists strive to initiate methods that are culturally appropriate, sensitive to local norms and policies, and field friendly. Using non-invasive methods to answer bioanthropological research questions allows researchers to conduct important research such as that described in this dissertation, among vulnerable and non-WEIRD communities including children. Furthermore, the individualized data produced by these methods provides an opportunity for improved community and participant engagement and the application of the findings. Investigators can produce personal reports for participants, along with summary statistics for the sample and sub-sample groups to be provided to community stakeholders, organizations, and interested individuals. This knowledge sharing not only gives back to the communities and participants but can empower them through its ability to inform and potentially motivate social action and policy change. Additionally, because the wristbands measure at the individual level, something not achieved by traditional environmental sampling techniques, the data can expose inequalities within and between spaces further informing policymakers as to which groups and communities are most vulnerable and in need of interventions (see below for the details of how I apply the dissertation results).

An additional and major contribution of this work is the data that it produces, as only two other investigations have been published that provide pesticide concentration data among human samples using silicone wristbands. Because the method is so new, and researchers are only beginning to use it to measure pesticides, this dissertation will contribute to the creation of reference data that future analyses may compare to. As of now, no reference exists for human exposure to pesticides using silicone wristbands. The previous studies were conducted among a sample of farm working adults in West Africa (Donald et al., 2016) and adolescent Latina girls in California (Harley et al., 2019). While both studies provide invaluable data and a methodological framework, there are also limitations. Donald et al., (2016), provided the first published report of pesticide concentrations using silicone wristbands. They tested for 63 pesticides/metabolites, including legacy OCPs and current-use chemicals. However, only 35 out of 70 participants obtained 100% compliance and only detected 26 pesticides overall (Donald et al., 2016). In Harley et al., (2019), researchers explored 10 legacy- and 15 current-use pesticides/metabolites used in agriculture and/or residentially among girls aged 14 to 16 in an agricultural region of California. The study tested for much fewer pesticides and metabolites (e.g., did not test for some persistent organochlorine pesticides like DDT and Lindane) compared to the dissertation and Donald et al., did not use log-transformations of the data, and detection frequencies were on average lower than those presented in this dissertation (only one pesticide, Fipronil sulfide, was detected at above 56%)(Harley et al., 2019). Thus, the relatively high compliance, detection frequencies, and expansiveness of the pesticides tested for and detected in this dissertation makes important headway in the development of a reference dataset for continued work.

Community Engagement and Broader Impacts

This project was designed and implemented as a community-engaged project in collaboration with the community of Sarapiquí, including local stakeholders and the Organization for Tropical Studies La Selva station, as well as larger Costa Rican institutions including the Ministry of Health, El Patronato Nacional de la Infancia (PANI), and the University of Costa Rica (UCR). With the support of Indiana University's Department of Anthropology SKOMP feasibility research grant, I brought the initial research question—the relationship between pesticide exposure and pubertal timing among girls—to the community in 2019. I met with leaders of the Organization for Tropical Studies (OTS) and school directors to ask if the research topic would be a) fitting for the area and communities and b) of interest to the community. It was important for me to develop a dissertation project that would provide data of value and interest to the community as well as one that would fulfill a research need (and knowledge gaps) related to an important social/environmental justice issue. I wanted to do research that mattered, in all aspects. When the community members and stakeholders showed unanimous interest in the topic and assured me of its value to the community and Costa Rica more largely, I got to work on developing the research proposal and plan in partnership with OTS. Thus, since the start of the project, OTS has been involved in the research.

The proposal and plans went through various rounds of changes in working with the Ministry of Health, UCR, and PANI, until it was approved by all three institutions. Once approved and I was in the field, I hired two local female research assistants who I trained on research methods including recruitment, interviews, survey, anthropometrics, and data entry and management. I tested the instruments among them to further ensure cultural appropriateness and correct language use. My assistants developed valuable skills and expanded their community and institutional networks through their involvement with the project. One went on to secure a permanent position as the assistant academic coordinator at OTS partially because of her involvement with the dissertation. She also co-attended the Wallace Scientific Conference at the Tropical Agricultural Research and Higher Education Center (CATIE) where we co-presented our research findings related to food insecurity in Sarapiquí.

Since finalizing the data and quantifying the results, I have been dedicated to distributing the findings to participants, local organizations, and additional interested community members. For all participants and stakeholders, I created and distributed a one-page summary of the findings (Appendix Figure 1). For each participant with chemical exposure data, I created an individual (personalized) report of the chemical concentrations detected from their wristbands as well as information regarding the chemical itself such as class, use, and known health risks (see Appendix Figure 2). I also provided a summary of their dietary nutritional data from the 24-hour dietary recall. This was delivered and explained to participants, the PANI office in Sarapiquí, local primary and secondary schools, OTS, the Sarapiquí Learning Center, and the Sarapiquí Guia Scouts organization. The final dissertation (once approved) will be converted into a technical report with policy recommendations to be delivered to the Ministry of Health, Ministry of Agriculture, Ministry of Environment, CATIE, and UCR.

The high prevalence of food insecurity discovered through this dissertation motivated conversations with community members and organizations, which has subsequently led to the development of a community-based initiative to tackle food insecurity through a school agroecological learning program. The plans for the project are being finalized with Lapa Verde—a local organization that focuses on sustainability and community outreach—which will own and manage the project. We plan to submit the grant proposal to the Inter-American Foundation this year. The project will have three main goals. First, to improve food insecurity among students and their families through sustainable growing practices and provisioning of nutritious, organic, and culturally- and ecologically appropriate foods. Second, the project will teach knowledge including environmental science, nutrition, and health, while youth obtain valuable skills including practical agroecological abilities as well as employable skills such as teamwork, leadership, engineering, and problem-solving. Finally, we hope the project through engaged learning and improved food security will reinstitute a culture of local, small-scale, organic, and sustainable growing. This culture has been lost among recent generations.

Future Directions

I plan to use my experience and additional data gained from this dissertation project to continue asking questions and disseminating findings to both scholarly and general audiences. Soon, I will submit an invited paper on the silicone wristband methodology and its potential for human biologists to the American Journal of Human Biology. This manuscript will include a case study of the relationships between polybrominated diphenyl ethers, a class of toxic flame retardants that were also estimated using the subsample of wristbands from my sample, and growth and puberty. I also plan to evaluate current-use pesticide classes (e.g., organophosphate, triazine) and whether they associate with age at thelarche and menarche in collaboration with the Venier lab at Indiana University. This forthcoming analysis was recently decided after conversations with mentor Marta Venier regarding the large variety of compounds within CUPs and potential compound-based effects on human biology. Lastly, I plan to analyze and publish themes from the ethnographic and qualitative data not presented in this dissertation. I aim to use the qualitative data in combination with the quantitative to findings to highlight the lived experiences of the participants and community members, tell their stories, and to build public-facing reports, press releases, non-academic web articles, and policy recommendations.

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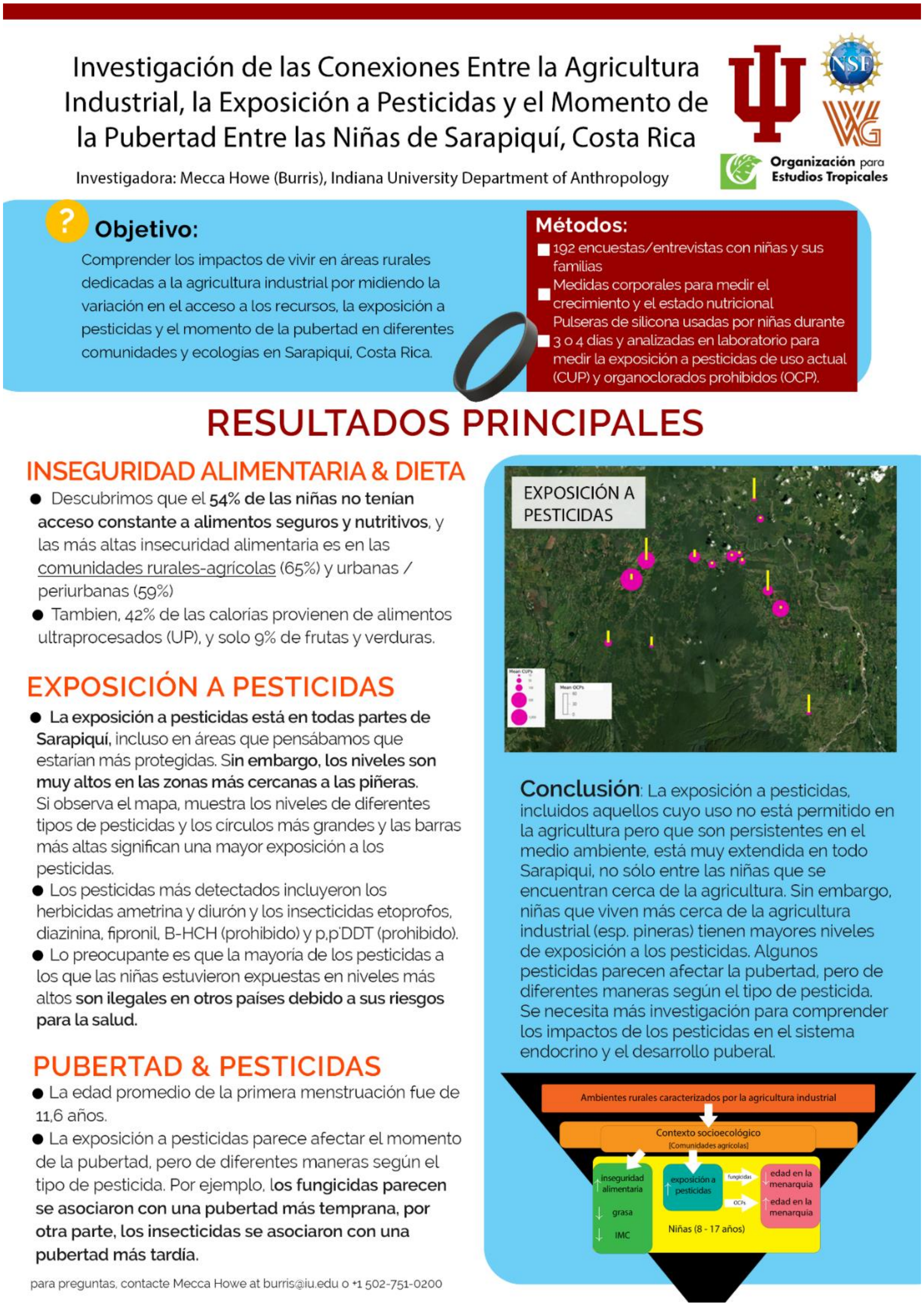
APPENDIX

Dissemination Materials



Investigación de las Conexiones Entre la Agricultura Industrial, la Exposición a Pesticidas y el Momento de la Pubertad Entre las Niñas de Sarapiquí, Costa Rica

Investigadora: Mecca Howe (Burris), Indiana University Department of Anthropology

Organización para Estudios Tropicales

Objetivo:

Comprender los impactos de vivir en áreas rurales dedicadas a la agricultura industrial por midiendo la variación en el acceso a los recursos, la exposición a pesticidas y el momento de la pubertad en diferentes comunidades y ecologias en Sarapiqui, Costa Rica.

Métodos:

- ■ 192 encuestas/entrevistas con niñas y sus familias
- ■ Medidas corporales para medir el crecimiento y el estado nutricional
- ■ Pulseras de silicona usadas por niñas durante 3 o 4 dias y analizadas en laboratorio para medir la exposición a pesticidas de uso actual (CUP) y organoclorados prohibidos (OCP).

RESULTADOS PRINCIPALES

INSEGURIDAD ALIMENTARIA & DIETA

- Descubrimos que el **54% de las niñas no tenían acceso constante a alimentos seguros y nutritivos**, y las más altas insecuridad alimentaria es en las comunidades rurales-agrícolas (65%) y urbanas / periurbanas (59%)
- Tambien, 42% de las calorias provienen de alimentos ultraprocesados (UP), y solo 9% de frutas y verduras.

EXPOSICIÓN A PESTICIDAS

- **La exposición a pesticidas está en todas partes de Sarapiquí**, incluso en áreas que pensábamos que estarian más protegidas. S**in embargo, los niveles son muy altos en las zonas más cercanas a las piñeras.** Si observa el mapa, muestra los niveles de diferentes tipos de pesticidas y los circulos más grandes y las barras más altas significan una mayor exposición a los pesticidas.
- Los pesticidas más detectados incluyeron los herbicidas ametrina y diurón y los insecticidas etoprofos, diazinina, fipronil, B-HCH (prohibido) y p,p'DDT (prohibido).
- Lo preocupante es que la mayoria de los pesticidas a los que las niñas estuvieron expuestas en niveles más altos **son ilegales en otros países debido a sus riesgos para la salud.**

PUBERTAD & PESTICIDAS

- La edad promedio de la primera menstruación fue de 11,6 años.
- La exposición a pesticidas parece afectar el momento de la pubertad, pero de diferentes maneras según el tipo de pesticida. Por ejemplo, l**os fungicidas parecen se asociaron con una pubertad más temprana, por otra parte, los insecticidas se asociaron con una pubertad más tardía.**

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Conclusión: La exposición a pesticidas, incluidos aquellos cuyo uso no está permitido en la agricultura pero que son persistentes en el medio ambiente, está muy extendida en todo Sarapiqui, no sólo entre las niñas que se encuentran cerca de la agricultura. Sin embargo, niñas que viven más cerca de la agricultura industrial (esp. pineras) tienen mayores niveles de exposición a los pesticidas. Algunos pesticidas parecen afectar la pubertad, pero de diferentes maneras según el tipo de pesticida. Se necesita más investigación para comprender los impactos de los pesticidas en el sistema endocrino y el desarrollo puberal.

Figure 1. Summary of results distributed to participants, community organizations, schools, and

stakeholders

Resultados de exposiciones químicas individuales					
Participante	#19	**Passive sampler:** silicone wristband (pulsera de silicona)			
Localidad:	El Tigre, Sarapiquí, CR	**Dates worn:** 11/5/2022 – 15/5/2022			
Recogido por:	Mecca Howe Burris, Indiana University	**Protocol #**: IU-10654; UCR-CEC-111-2022			
Información de datos:	Los datos fueron extraídos y procesados mediante cromatografía de líquidos y gases-espectrometría de masas por Mecca Howe Burris en la Universidad de Indiana Bloomington en el Laboratorio de Química Ambiental de Hites bajo la supervisión de la química Dra. Marta Venier. Las cantidades finales fueron calculadas por los químicos Dr. Kevin Romanak y Dr. Chunjie Xia. Los datos se clasifican utilizando las fuentes enumeradas en la página final.				
Abreviaturas:	INS = insecticida; HER = herbicida; FUNG = fungicida; PBDE = retardante de llama bromados; ng/g = nanogramo por gramo				
Clase de peligro	Rojo = muy-moderadamente; Amarillo = moderadamente-agudo; verde = poco				
Peligo y Nombres		**Tipo**	**# ng/g**	**Uso común**	**Peligro**
Clordanos **Nombres comerciales: Clordano, Comejenol, Octachlor, Velsicol 1068** ***--Prohibido--***	trans-Nonachlor *(trans-nonachlordano ; cis-nonachlordano)*	INS	3,80	termitas subterráneas, insectos domésticos, plagas de animales y preservar maderas.	Moderadamente peligroso/tóxico (OMS); Toxicidad tópica: capacidad irritativa: ocular positiva (severa); dérmica positiva (leve). Toxicidad crónica y a largo plazo: neurotoxicidad, Probable carcinógeno humano, disrupción endocrina, reducción de la fertilidad, Parkinson, y efectos en el desarrollo. Es tóxico para el sistema hematopoyético, hígado y el sistema digestivo. Produce hemorragias nasales y oculares,
	Gama-Chlordane *(gama-clordano)*		0		

					anemia aplásica y leucemia aguda, disminuye la efectividad de anticoagulantes. Enfermedad de los trabajadores agrícolas, trastorno de ansiedad, asma, diabetes, hipertiroidismo, infertilidad masculina, inflamación, trastornos de la memoria, trastornos motores, defectos cromosómicos, tumores testiculares y rectales. Muy tóxico para organismos acuáticos.
Hexaclorobenceno (HCB) **Nombres comerciales: Hexachlorobenzene, Perchlorobenzene, Perclorobenceno, Anticarie, Sanocide, Bunt-cure,Amatin, y otros.** ***--Prohibido--***		FUNG	0	Era un pesticida para proteger las semillas de cebollas y sorgo, trigo y otros granos contra los hongos hasta 1965. También se usaba para fabricar fuegos artificiales, municiones y caucho sintético. Ser uno de los	Toxicidad aguda. Es un conocido carcinógeno hepático. Provoca daños en los órganos tras exposiciones prolongadas o repetidas incluyendo el hígado, la tiroides, el sistema nervioso, los huesos, los riñones, la sangre y los sistemas inmunológico y endocrino. En Centroamérica es conocido por: Costa Rica: tener antecedentes de exposición de los padres a este plaguicida en un estudio de leucemia infantil. Provoca lesiones dermatológicas, hiperpigmentación, hipertricosis, agrandamiento del hígado, agrandamiento de la glándula tiroides y

				componentes del "Agente Blanco", del "Agente Púrpura" y del "Agente Azul" utilizados en la guerra de Vietnam. Su uso está prohibido desde 1984 en virtud del Convenio de Estocolmo sobre contaminantes orgánicos persistentes.	los ganglios linfáticos y osteoporosis o artritis, principalmente en niños. Los bebés amamantados de madres expuestas al hexaclorobenceno pueden desarrollar un trastorno mortal llamado pembe yara (llaga rosada). Otros efectos crónicos: asociado con riesgo de diabetes, tumores de mama, retraso del crecimiento fetal, trastorno de ansiedad general, trastornos del crecimiento, infertilidad en las mujeres y enfermedad renal. Muy tóxica para la vida acuática.
Heptacloro **Nombres comerciales: Clorahep, Drinox, Heptagran, Heptamul, Heptox, Velsicol, Basaklor, Soleptax, Termide** ***--Prohibido--***	Heptachlor Epoxide *(Epóxido de heptacloro)*	INS	0	control de termitas, hormigas, insectos del suelo y tratamiento de semillas.	Moderadamente tóxico. Irritativa dérmica. Toxicidad crónica y a largo plazo: neurotoxicidad (colinérgica); mutagenicidad; Posible carcinógeno en humanos (IARC, EPA) incluyendo Leucemia y hígado; disrupción endocrina; Parkinson, hepatotóxico, nefrotóxico y catarata, carcinoma hepático.

					Muy tóxico para organismos acuáticos.
Lindano **Nombres comerciales: Gamma-Dhc, Lindane, Matacresa, Srew Worm, Gammaxene** ***--Prohibido--***	a-HCH *(a-hexaclorociclohexano)*	INS	0	control de insectos de suelo, tratamiento de semillas, plagas domésticas y de salud pública especialmente para el control de piojos y sarna.	Contaminante orgánicos persistente. Moderadamente peligroso/tóxico (OMS). Toxicidad tópica: capacidad irritativa: ocular positivo (leve); dérmica positiva (leve). Toxicidad crónica y a largo plazo: neurotoxicidad: nivel 3; enfermedad de alzheimer; efecta el hígado y los riñones; Posible carcinógeno humanos; disrupción endocrina: disminuye la producción de esperma; genotoxicidad; Parkinson; otros efectos crónicos: cirrosis y hepatitis crónica, rinitis, eczema, conjuntivitis, cáncer cerebral y anemia aplásica. Riesgo de efectos graves para la salud en caso de exposición prolongada por ingestión. Puede perjudicar a los niños alimentados con leche materna. Muy tóxico para
	b-HCH *(b-hexaclorociclohexano)*		0,71		
	d-HCH *(d-hexaclorociclohexano)*		0,77		

					organismos acuáticos, abejas, y aves
Dieldrín **Nombres comerciales: Dieldrin, HEOD, Aldrin** ***--Prohibido--***	*hexacloro-1,3-ciclopentadieno con norbornadieno y un peroxiácido tal como ácido peracético.*	INS	0	control de insectos del suelo, termitas, hormigas, y pulgas; preservar madera.	Contaminante orgánicos muy persistente. Extremadamente peligroso y tóxico. Toxicidad crónica y a largo plazo: neurotoxicidad: nivel 2; teratogenicidad; mutagenicidad; Probable carcinógeno humano–cáncer de mama, tumores de pulmón, hígado, tiroides y glándulas suprarrenales. Disrupción endocrina; genotoxicidad: asociado con depresión, enfermedad de los trabajadores agrícolas, diabetes, infertilidad femenina, condiciones precancerosas, convulsiones y Parkinson; otros efectos crónicos: trastornos inmunológicos; se acumula en los tejidos, especialmente en el tejido adiposo. Muy tóxico en contacto con la piel. Tóxico, riesgo de efectos graves para la salud en caso de exposición prolongada por ingestión incluyendo dañan el sistema nervioso, el hígado y el sistema inmunológico. Conocido

					por: ser neurotóxico; los órganos blanco son el sistema nervioso central y el hígado. Toxica extrema para organismos acuáticos incluyendo peces y anfibios, y alta para abejas.
DDT **Nombres comerciales: Digmar, DDT** ***--Prohibido--***	o,p-DDT *(diclorodifeniltricloro-etano)*	INS	0	Alguna vez fue un pesticida muy utilizado, pero hoy su uso agrícola ha sido prohibido en todo el mundo debido a su toxicidad y tendencia a bioacumularse. Pero hoy, se usan para el control del mosquito transmisor de la malaria y	Contaminante orgánicos muy persistente. Es esencialmente no biodegradable, se degrada a DDE y a DDD, metabolitos que también son extremadamente persistentes. Moderadamente peligroso/tóxico (OMS). Toxicidad crónica y a largo plazo: neurotoxicidad, depresión psicológica; dermatitis; Carcinógeno en humanos (especialmente hígado y leucemia); disrupción endocrina; Parkinson; otros efectos crónicos: asociado con riesgo de diabetes, pérdida de embriones, formación de células precancerosas, hipertensión, resistencia
	p,p-DDT *(diclorodifeniltricloro-etano)*		8,33		

				otros insectos.	a la insulina, trastornos cromosómicos, pubertad temprana, anomalías congénitas, nacimiento prematuro convulsiones, enfermedad del hígado graso. Se deposita y acumula en los tejidos, principalmente en el graso. Se excreta a través de la leche humana y atraviesa la membrana placentaria. Tóxico por ingestión. Tóxico, riesgo de efectos graves para la salud en caso de exposición prolongada por ingestión–causa daño a los órganos, especialmente tumores hepáticos. Costa Rica: tener antecedentes de efectos neurotóxicos en los trabajadores que lo aplicaron para combatir la malaria durante los años 60 y 70 (1998). Muy tóxico para organismos acuáticos
	p,p-DDE *(diclorodifenildicloro-etileno)*	INS	1,39	es un producto de degradación del DDT	
	p,p-DDD (dichlorodiphenyldichloroethane)	INS	0,63	Es un metabolito del DDT	

Endosulfan **Nombres comerciales: Barredor, Endosan, Endosulfan, Galgofan, Isolan, Luxan, Nebution, Phaser, Semellin, Tafoltan, Thiodagro, Thiodan, Thionex.** ***--Prohibido--***	Endosulfan II *(6-hydroxy-1-methyl-1,2,3,4-tetrahydro-beta-carboline)*	INS	0	contra ácaros e insectos chupadores, masticadores y barrenadores en muchos cultivos; preservar la madera.	Persistencia en el suelo. Moderadamente peligroso y Altamente tóxico (OMS). Neurotoxicidad; disrupción endocrina: disminución de la cantidad de espermatozoides y aumento de las formas anormales; aberraciones cromosómicas e aductos de ADN; Parkinson; otros efectos crónicos: nefrotóxico, hepatotóxico, toxicidad paratiroidea, pérdida de la memoria y daño cerebral difuso, en animales se ha reportado ceguera, la cual se revierte cuando cesa la exposición. Asociado con enfermedades cardiovasculares, tumores de mama en hombres, enfermedad renal crónica, hemorragia, hipertensión, infertilidad, hipopigmentación, problemas de aprendizaje, trastornos motores, anomalías musculoesqueléticas, convulsiones. En Centroamérica es conocido por: causar la mayoría de las intoxicaciones.

					Tóxica extrema para organismos acuáticos.
CIAT Nombres comerciales: Desetil atrazina, deethylatrazine, deetilatrazina, 6-Cloro-N2-isopropil-1,3,5-triazina-2,4-diamina, 2-Cloro-4-amino-6-(isopropilamino)-s-triazina, atrazina desetil, 6-cloro-N-(propan-2-il)-1,3,5-triazina-2,4-diamina		HER	0	control pre y postemergente selectivo de malezas gramíneas y de hoja ancha en banano, caña de azúcar, forestales, macadamia, maíz, sorgo, palma de aceite y piña.	Moderadamente tóxico. Irritante. Tóxico para la reproducción. Tóxico para los organismos acuáticos y el medio ambiente. Próstasis. Interfiere con el desarrollo del sistema gonatrópico pituitario en dosis altas.

Atrazina **Nombres comerciales: Atrazine, Amezol, Atracoop, Atralaq, Atranex, Atrazina, Bayprim, Crisazina, Drexel Atrazina, Gesaprim, Gramyprin, Igual, Limpiamaiz, Mazorca, Noval, Novazina, Reprim, Sanazine, Sertranex, Shell Atrazina, Sinazine, Sutrazina**		HER	0	control pre y postemergente selectivo de malezas gramíneas y de hoja ancha en banano, caña de azúcar, forestales, macadamia, maíz, sorgo, palma de aceite y piña.	Moderately peligroso y tóxico (EPA). Capacidad irritativa: ocular positiva (severa); dérmica positiva (leve); capacidad alergénica: positiva (humanos). Toxicidad crónica y a largo plazo: neurotoxicidad, disrupción endocrina, Posibilidad de sensibilización en contacto con la piel. Provoca daños en los órganos tras exposiciones prolongadas o repetidas. Hay pruebas suficientes en animales de experimentación de la carcinogenicidad de la atrazina. En concreto, la atrazina provoca tumores mamarios en hembras. También afecta las vías nuerodocrinas del hipotálamo, lo que provoca una pubertad temprana y convierte a los animales machos (p. ej., ranas) en hembras. Se ha asociado con enfermedades de la corteza suprarrenal, enfermedades de los trabajadores agrícolas, lesiones cerebrales, cardiotoxicidad, trastornos cognitivos, tumores de colon, diabetes, retraso del crecimiento fetal,

					resorción fetal, enfermedades genitales en hombres, enfermedades del cabello, inmunodeficiencia, infertilidad masculina, enfermedades renales, Trastornos de la memoria, menstruación irregular, trastornos de las habilidades motoras, enfermedades musculares, daño a los nervios, Parkinson secundario, enfermedad de la próstata y rinitis. Muy tóxico para organismos acuáticos.
Acetamiprid **Nombres comerciales: Acetazell, Aval, Cormoran, Esiom, Mospilan, Rescate**	*N-[(6-chloro-3-pyridyl)methyl]-N’-cyano-N-methyl-acetamidine*	INS	0	control de insectos en cultivos como hortalizas de hojas verdes, cítricos, frutas de pepita, uvas, algodón, coles y plantas ornamentales	Tóxica aguda y crónica. Irritante. Disrupción endocrina; reducción en la apertura del prepucio y la apertura vaginal en ratas; vacuolización hepatocelular en animales de experimentación. Otros efectos crónicos: Trastornos de la conciencia, hemorragia, hiperglucemia, hipotensión, enfermedad renal, cirrosis hepática, anorexia. Tóxica para las 229bejas.

Ametrina Nombres comerciales: Ametryn, Agromart, Ametrex, Ametrina, Ametrol, Ametrol Fácil, Ametryn, Amigan, Amezol, Bioquim Herbastop, Crisantrine, Cristal, Gesapax, Maitrina, Marmatrina, Novatrina, Shevametrex, Sugarpax, Uranus	*2-(methylsulfanyl)-1,3,5-triazine*	HER	1,80	control pre o postemergente temprano de gramíneas y malezas de hoja ancha en banano, cacao, café, caña de azúcar, cítricos, maíz, palma de aceite y piña.	Ligeramente peligroso (OMS). Ligeramente tóxico (EPA).Ccapacidad irritativa ocular y dérmica. Todavía no hay muchos datos sobre toxicidad crónica o enfermedades crónicas. Asociado con anomalías cardiovasculares, neoplasias hepáticas, defectos cromosómicos y anomalías musculoesqueléticas en estudios con animales y de laboratorio.

Carbaril Nombres comerciales: Carbaryl, Agromart Bpohy Carbaril, Carbamide, Cebicid, Devicarb, Disavin, Hormitox, Sevin, Starex, Ravyon		INS	0,23	control de Lepidóptera, Coleóptera e insectos chupadores en muchos cultivos y de ectoparásitos.	Moderadamente peligroso y tóxico (OMS). Acción tóxica y síntomas: síndrome tóxico por inhibidores de la colinesterasa (Dolores de cabeza, pérdida de memoria, debilidad y calambres musculares y anorexia). Toxicidad tópica: capacidad irritativa: ocular positiva (moderada); dérmica positiva (leve). Toxicidad crónica y a largo plazo: neurotoxicidad, teratogenicidad (malformaciones esqueléticas), mutagenicidad: positiva: aunque el carbaril es ligeramente mutagénico, en humanos puede reaccionar con nitritos encontrados en aditivos alimentarios, produciendo nitroso carbaril, el cual es altamente mutagénico; probable canrcinógeno humano (EPA) particularmente vasos sanguíneos, riñón e hígado; disrupción endocrina: otros efectos reproductivos: aumento del porcentaje de espermatozoides anormales; otros efectos crónicos: asma, bronquitis, lesión

🟥					pulmonar, catalepsia, eccema, linfoma no Hodgkin, melanoma, rinitis, convulsiones, hepatotóxico y nefrotóxico, depresión del sistema inmune, anemia aplásica. En Centroamérica es conocido por: provocar dermatitis de contacto. Muy tóxico para organismos acuáticos. Toxicidad aguda – alta para ambiente incluido peces, aves, abejas, lombrices, y plantas. Efectos ambientales en Centroamérica: Costa Rica: determinado en el 2001 en muestras de agua superficial de canales, quebrada y río de áreas de cultivo de piña en Pocora, Siquirres.

Diuron **Nombres comerciales: Atrex, Batazo, Bioron, Crisapon, Direx, Diumar, Diurex, Diurolaq, Diuron, Drexel, Dorac, Duirolaq, Hierbatox, Karmex, Killuron, Kovar, K-Suron, Novaron, Sanduron, Senduron**		HER	2.97	control pre y postemergente temprano selectivo de malezas de hoja ancha y gramíneas en algodón, banano, caña de azúcar, maíz, sorgo, piña, cítricos y áreas no cultivadas.	Ligeramente tóxico (EPA). Acción tóxica y síntomas: síndrome tóxico por derivados de la urea. Toxicidad tópica: capacidad irritativa: ocular positiva (leve); dérmica positiva (leve); capacidad alergénica: positiva (leve). Toxicidad crónica y a largo plazo: teratogenicidad (anormalidades esqueléticas); mutagenicidad: no es clara; probable carcinogenicidad (EPA); disrupción endocrina; no hay mucho dato en otros 233bejas233 crónicos otros pero ha asociado con metahemoglobinemia y riesgo de efectos graves para la salud en caso de exposición prolongada incluyendo enfermedad de la vejiga urinaria, neoplasias de la vejiga, hiperplasia, necrosis, papiloma. Muy tóxico para organismos acuáticos y mediana tóxico para abejas y aves. Reportado en aguas superficiales provenientes de zonas de cultivo de piña en Sarapiquí (2002) y otros lugares del Caribe, Pocora Siquirrez, Rio

					Sixaola, y Cartago (2006-2008)
<u>Matalaxil</u> **Nombres comerciales: Abak, Apron, Mefonoxan, Metalaxyl, Pilarxil, Ridomil**		FUNG	0,23	control de enfermedades fungosas causadas por peronosporales en agricultura – mas común: algodón, cítricos, maíz, papa, sorgo, tabaco, hortalizas y cucurbitáceas.	Ligeramente peligroso (OMS) y Moderamente tóxico (EPA). Acción tóxica y síntomas: síndrome tóxico por anilida. Toxicidad tópica: capacidad irritativa: ocular positiva (leve); dérmica positiva (leve) No hay muchos datos sobre toxicidad crónica: genotoxicidad, hepatoxócio, posibilidad de sensibilización en contacto con la piel, trastorno depresivo, y enfermedades de los trabajadores agrícolas. Nocivo para organismos acuáticos.

Azoxistrobina **Nombres comerciales: Amistar, Azoxistrobina, Azoxystrobin**		FUNG	1,77	control de enfermedades fungosas en muchos cultivos como arroz, café, cebolla, chile, cítricos, frijol, melón, ornamentales, repollo, tomate, papa, pepino, sandía, arveja china, zanahoria, apio y semilleros de tabaco.	No peligro agudo (OMS); nd (EPA). Tóxico si se ingiere. Acción tóxica y síntomas: información limitada sobre los efectos en la salud humana. Produce irritación de la piel y posible sensibilización. Toxicidad tópica: capacidad irritativa: ocular positiva (leve); dérmica positiva (leve). Muy tóxico para organismos acuáticos.
Boscalid **Nombres comerciales: Endura, Nicobifen, Emerald, Pristine, Cantus, Anilide**	*2-chloro-N-(4-chlorobiphenyl-2-yl)nicotinamide* *boscalid*	FUNG	0,45	para control de mildius en varios cultivos	Ligeramente tóxico (EPA). Boscalid puede ser genotóxico y citotóxico in vitro en linfocitos de sangre periférica humana, pero tiene baja toxicidad en estudios con animales. Acción tóxica y síntomas: síndrome tóxico por anilida. Toxicidad tópica: capacidad irritativa: ocular positiva (leve); dérmica positiva (leve). Toxicidad crónica y a largo plazo: abortos en conejos, toxicidad

					hepática y adenoma folicular de la glándula tiroides en animales, evidencia sugestiva de carcinogenicidad, pero no suficiente para evaluar el potencial carcinógeno humano. Asociado con intolerancia a la glucosa, hiperglucemia, hiperpigmentación, resistencia a la insulina, trastornos del movimiento y malformaciones del sistema nervioso.
Etroprofos **Nombres comerciales : Ethoprophos, Etoprop, Mocap**		INS	30,01	control de nematodos e insectos del suelo en diversos cultivos	Extremadamente peligroso y tóxico (OMS). Acción tóxica y síntomas: síndrome tóxico por inhibidores de la colinesterasa. Toxicidad tópica: capacidad irritativa: ocularpositiva; dérmica positiva. Toxicidad crónica y a largo plazo: neurotoxicidad (colinérgica); probable carcinogenicidad; otros efectos crónicos: puede causar dermatosis. Tóxico por ingestión y muy tóxico por inhalación y en contacto con la piel. Posibilidad de sensibilización en contacto con la piel. En Centroamérica es conocido por: causar la mayoría de las

					intoxicaciones y muertes. Costa Rica: estar presente en el polvo de casas y escuelas que colindan con una plantación de banano en Limón (2002). Muy tóxico para organismos acuáticos. Extrema-mediana para custáceios, aves, abejas, lombrices, plantas. En Costa Rica, ha detectado en agua para consumpo en muchos lugares donde hay cultivos.
Malatión **Nombres comercials: Malathion, Belation, Conservo-Tox, Dosema, Fyfanon, Inithion, Insection, K-Thion, Lucathion, Lufanex, Marmathion, Marmation, Mata Piojos, Rimalation, Tubo Mata Picudo**		INS	0,30	control de ácaros e insectos chupadores y masticadores en algodón, arroz, papa, hortalizas y granos almacenados; ectoparásitos en animales y humanos. Usa para salud pública, también.	Ligeramente peligroso y tóxico (OMS). Irritativa: ocular positiva (moderada); dérmica positiva (leve); capacidad alergénica: positiva (leve). Toxicidad crónica y a largo plazo: neurotoxicidad (neuropatía retardada); mutagenicidad, carcinogenicidad: evidencia sugestivo (EPA); disrupción endocrina; genotoxicidad (aberraciones cromosómicas); Parkinson: asma, lesión renal, bronquitis crónica, tumores de mama, colon, hígado y próstata, sordera, depresión, diabetes tipo 2, gliosis, intolerancia al

🟥					gluten, hiperglucemia, hipertiroidismo, infertilidad masculina, inflamación, resistencia a la insulina, leucemia no Hodgkin Linfoma, enfermedades del sistema nervioso, rinitis y enfermedades testiculares. Otros efectos crónicos: puede alterar el sistema inmunológico, hígado, glándulas suprarrenales, células sanguíneas, órganos de los sentidos, neuropatía periférica y cambios conductuales. En Centroamérica es conocido por: Costa Rica: tener antecedentes de exposición de los padres a este plaguicida en un estudio de leucemia infantil. Causar intoxicaciones de niños de escuela y de mujeres trabajadoras en finca de algodón. Nicaragua: estar relacionado con el déficit en el aprendizaje verbal inmediato y el desempeño visomotor. Muy tóxico para organismos acuáticos. Extrema -mediana para peces, aves, abejas, algas.

Alachor Nombres comerciales: Alachlor, Alanex, Disaclor, Lasso, Lazo		HER	0,0	control preemergente selectivo de malezas gramíneas y de hoja ancha en algodón, frutales, ornamentales, tabaco y hortalizas.	Ligeramente peligroso y tóxico (OMS). Toxicidad tópica: capacidad irritativa: ocular negativo; dérmica positiva (moderada); capacidad alergénica: positiva. Toxicidad crónica y a largo plazo: disrupción endocrina; toxicidad materna y fetal en animales de experimentación; genotoxicidad (aberraciones cromosómicas); Posibles efectos carcinógenos particularmente colon, hematológico, leucemia, nasal y tiroides. Asociado con insuficiencia renal, mieloma múltiple, hipotiroidismo, infertilidad masculina, diabetes, aborto espontáneo, dematitis y enfermedades de los trabajadores agrícolas Muy tóxico para organismos acuáticos.
Metolaclor Nombres comercials: Dual, Dual Gold, Metolacloro, Metolachlor, Pennant, Codal, Dual Triple, Dual II, Metelilachlor, Humextra, Metoken,		HER	0,0	control selectivo de algunas malezas de hoja ancha y gramíneas anuales en algodón, caña de azúcar, maíz, sorgo,	Ligeramente peligroso y tóxico (OMS). Tatal si se inhala. Irritativa: ocular positiva (leve); dérmica positiva (leve); capacidad alergénica: positiva. Toxicidad crónica y a largo plazo: posible carcinógeno humano, específicamente en el hígado; Daño al sistema nervioso y alteración

Jindual, Bicep, Turbo				entre de los otros.	endocrina en humanos.asociado con pérdida fetal en estudios con animales, cianosis, infertilidad masculina, insuficiencia renal, tumores de pulmón, linfoma, pubertad temprana y rinitis. Muy tóxico para organismos acuáticos. 240beja tóxico para otros animales y insectos.
Acetolacloro Nombres comercials: Galgoclor, Harness, Relay, Acetochlor, Nevirex, Acenit, Erunit,		HER	0,0	Control preemergente selectivo de gramíneas anuales y algunas malezas de hoja ancha en maíz, maní, soya, algodón, papa y caña de azúcar.	Ligeramente peligroso y tóxico (OMS). Capacidad irritativa: ocular positiva (leve); dérmica positiva (leve); capacidad alergénica: positiva. Toxicidad crónica y a largo plazo: probable carcinógeno humano, disrupción endocrina, toxicidad renal, oligoespermia, atrofia testicular y nefritis intersticial, puede causar irritación respiratoria; asociado con pérdida fetal y defectos cardíacos en estudios con animales. Muy tóxico para organismos acuáticos.

Propiconazole Nombres comerciales: Propicon, Propiconazol, Propilaq, Propizole, Tilt ,Banner, Desmel, Orbit, Bamper, Propimax, Wocosin		FUNG	0,11	control de enfermedades causadas por un amplio rango de hongos en cultivos como banano, plátano, café y arroz	Moderadamente peligroso y tóxico (OMS). Toxicidad tópica: capacidad irritativa: ocular positiva (moderada); dérmica positiva (moderada); capacidad alergénica: positiva. Toxicidad crónica y a largo plazo: Posible carcinógeno humano (EPA); disrupción endocrina; posibilidad de sensibilización en contacto con la piel. Se ha asociado con trastornos de ansiedad, depresión, trastornos cognitivos, daños y enfermedades hepáticas, tumores hepáticos, meningitis, trastornos motores y daños a los nervios.En Panamá: provocar dermatitis de contacto y presentar resultados de pruebas de parche positiva. Provoca deformaciones esqueléticas en animales recién nacidos. Muy tóxico para organismos acuáticos. Poco tóxico para otros como aves y algas. En Costa Rica: es uno de los ingredientes activos más detectados en agua superficial y sedimentos (especialmente cerca de las plantas empacadoras

					de banano) incluyendo Sarapiquí.
Diazinon **Nombres comercials: Basudin, Crisapon, Danol, Danon, Diazigran, Diazinon, Diazipolvo, Diazol, Dination, Dinazol, Disanon, Efective, Formuron, Hormi-kill, Knox-out, Pelotón, Piñorel, Rimazinon, River, Shevadiazol, Spectracide, Sundiazinon,**		INS	58,10	control de insectos chupadores, masticadores y ácaros en muchos cultivos, y ectoparasitida veterinario	Moderadamente peligroso y tóxico (OMS). Toxicidad tópica: capacidad irritativa: ocular positiva (leve); dérmica positiva (leve); capacidad alergénica: positiva (humanos). Toxicidad crónica y a largo plazo: neurotoxicidad, (colinérgica); teratogenicidad, (malformaciones esqueléticas); mutagenicidad, carcinogenicidad; disrupción endocrina; genotoxicidad: positiva (aberrac. Cromosómicas). Asociado con asma, trastornos del espectro autista, bronquitis

Vigilante, Zinoncoop.					crónica, daño hepático, trastornos cognitivos, depresión, diabetes, fibrosis, hemorragia, hepatitis, hiperglucemia, hipotensión, hipotiroidismo, infertilidad masculina, inflamación, resistencia a la insulina, leucemia, tumor pulmonar, linfoma, intelectual. Discapacidad, trastornos de la memoria, enfermedades pancreáticas, Parkinson, rinitis, convulsiones y temblores. Muy tóxico para organismos acuáticos, 243bejas, aves, lombrices.
Pyraclostrobina **Nombres comerciales: Regnum, Headline, Carbrio**	Pyraclostrobina y Pyraclostrobin-d6	FUNG	0,0	control de sigatoka en banano y plátano	Tóxico agudo. Irritativa 243bejas243 y ojos. Lesión hepática y renal en dosis altas. Muy tóxico para organismos acuáticos
Pendimetalina **Nombres comerciales: Pendimethalin, Garra, Garrolite, Gladiador, Gramilaq, Herbadox, Herbre, K-Bal, Panowol, Pendimetalin, Prowl,**		HER	0,40	control de gramíneas y malezas de hoja ancha anuales en algodón, arroz, cebolla, frutales, maíz, sorgo y tomate. Para el	Ligeramente peligroso y tóxico (OMS). Toxicidad tópica: capacidad irritativa: ocular positiva (moderada); dérmica positiva (leve). Prohibido en 243bejas. Toxicidad crónica y a largo plazo: neurotoxicidad: 243bejas243 carcinógeno humano. Otros efectos crónicos: toxicidad hepática,

Repose, Stomp, Sunmethalin, Toro, Penoxaline, Accotab, Wayup				control de chupones en tabaco.	aumento de la fosfatasa alcalina y tiroidea, asma y dermatitis. Asociado con enfermedad renal, tumores de pulmón, Parkinson y tumores de páncreas. Muy tóxico para organismos acuáticos. En Costa Rica: la fumigación de un campo de arroz provocó la muerte de peces y camarones en un río de Quepos (1987).
<u>Pyrethrin</u> Nombres comerciales : Pyrethrin I, Pyrethrin II, ENT 7,543,		INS	0	Control de una amplia gama de insectos y ácaros en salud pública, productos almacenados, casetas de animales y animales domésticos y de granja. Control de insectos masticadores y chupadores y arañas rojas. Repelentes personales de insectos y para el control de	Tóxico agudo. Irritativa ojos. La exposición prolongada en animales, incluidos perros, gatos y conejos, produce daños en las vías respiratorias y nasales, el hígado y el sistema nervioso. Puede provocar daños en los órganos tras exposiciones prolongadas o repetidas. Muy tóxico para organismos acuáticos y abejas.

				piojos humanos.	
Profenofos Nombres comerciales: Curacron, Ferticron, Polycron, Selecron		INS	0,14	para el control de insectos (lepidópteros) y ácaros en algodón, maíz, papa, hortalizas, tabaco y otros cultivos.	Moderadamente peligroso (OMS). Toxicidad tópica: capacidad irritativa: ocular positiva (moderada); dérmica positiva (leve). Toxicidad crónica y a largo plazo: neurotoxicidad; aborto espontáneo, enfermedades de la médula ósea, enfermedades hematológicas y temblor. Muy tóxico para organismos acuático, aves, y extrema para abejas.

Fipronil **Nombres comerciales: A.S. Myl, Albatros, Bemol, Blitz, Chipco Choice, Cosmos, Fulminante, Goliath Gel, Klap, Maxforce, Regent, Sofion, Termidor, Thunder, Tim-Bor, Tripzell, Weedcop, Zetanil.**		INS	1,04	control de múltiples especies de trips, gusanos de suelo y defoliadores, hormigas, termitas, minadores y otros insectos en un amplio rango de cultivos, foliarmente o incorporado al suelo.	Moderadamente peligroso y tóxico (OMS). Toxicidad tópica: capacidad irritativa: ocular positiva (leve); dérmica positiva. Toxicidad crónica y a largo plazo: Posible carcinógeno humano. Otros efectos crónicos: dermatitis, nefropatía crónica. Tóxico, riesgo de efectos graves para la salud en caso de exposición prolongada incluyendo daño a órganos. Asociado con lesión cerebral, daño hepático, anomalías congénitas, muerte, pérdida fetal, enfermedades hematológicas, infertilidad masculina, enfermedad renal, enfermedad hepática, daño nervioso, convulsiones y enfermedades testiculares. Muy tóxico para organismos acuáticos, 246bejas, y aves.
Prometón **Nombres comerciales: Pramitol, Gesafram**		HER	0,0	Matar malezas de hoja ancha anuales y perennes para ayudar en el control de malezas y pastos,	Tóxico agudo. Esta fórmula particular de prometón es fuertemente irritante para los ojos, la piel el tracto respiratorio. Muy tóxica para la vida acuática con efectos duraderos.

				principalmente en situaciones sin cultivos.	
Bromacil Nombres comerciales: Bromatel, Hyvar X, Krovar, Uragan, Borea, Borocil, Bromax, Cynogan, Hyvarex, Nalkil, Uragon, Urox, Du Pont herbicide 976		HER	0	control no selectivo de malezas en áreas no cultivadas y de malezas anuales en cítricos y piña.	Ligeramente tóxico (EPA). Toxicidad tópica: capacidad irritativa: ocular positiva (leve); dérmica positiva (moderada). Toxicidad crónica y a largo plazo: Posible carcinógeno humano (EPA); disrupción endocrina; daño en los testículos, hígado y tiroides en animales de laboratorio. Detectado también en aguas superficiales (canales, quebradas y río) de las zonas de cultivo de piña y de banano del Caribe costarricense (Sarapiquí, Pocora y Siquirres) entre 2001 y 2007. Muy tóxica para la vida acuática y abejas con efectos duraderos
Tiacloprid Nombres comerciales: Thiacloprid, Calypso		INS	0,0	control de insectos chupadores y mordedores (áfidos, mosca blanca, escarabajos, mariposas, minadores de hojas)	Moderadamente peligroso y tóxico (OMS). Muy peligrosa si se inhala. Toxicidad crónica y a largo plazo: neurotoxicidad, probable carcinogenicidad, particularmente tiroides, uterina, y ovario. Causa daño a los riñones. Asociado con enfermedad del hígado

				en diversos cultivos.	graso, intolerancia a la glucosa, hiperglucemia, resistencia a la insulina, enfermedad renal, temblores, y convulsiones. Puede dañar la fertilidad y el feto. Muy tóxico para organismos acuáticos, aves, y abejas.
Miclobutanil Nombres comerciales : Rally, Sisthane, Systhane, myclobutanil		FUNG	0,0	control de Ascomicetes, hongos imperfectos y Basidiomicetes en algodón, arroz, cucurbitáceas, maíz y ornamentales	Ligeramente peligroso y tóxico (OMS). Toxicidad tópica: capacidad irritativa: ocular positivo (leve). Posible riesgo durante el embarazo de efectos adversos para el feto. Se ha asociado con riesgo de infertilidad en los hombres, trastornos del desarrollo sexual y discapacidad intelectual, incluido el autismo. Muy tóxico para organismos acuáticos y aves.
Tebuconazol Nombres comerciales: Folicur, Orius, Silvacur, Tebuconazell, Tebucoz, Fenatrazole, Ethyltrianol, Etiltrianol, Tebuconazol, Elite		FUNG	0,0	control de Mycosphaerella fijiensis y otras enfermedades fungosas en banano y plátano; Alternaria solani en tomate y papa; y otros hongos en arroz, maní, ajo y	Ligeramente peligroso (OMS); Moderadamente tóxico (EPA). Toxicidad tópica: capacidad irritativa: ocular positiva (leve). Posible carcinógeno humano (EPA); disrupción endocrina. Posible riesgo durante el embarazo de efectos adversos para el feto. Asociado con calcinosis, disnea, feminización, retraso del crecimiento fetal, hemorragia, hepatomegalia, enfermedad renal,

🟥				ornamentales.	tumores hepáticos, enfermedades pulmonares, enfermedades de la placenta y condiciones precancerosas. Muy resistente a la hidrólisis y muy persistente en la interface agua sedimento. Tóxico para los organismos acuáticos, puede provocar a largo plazo efectos negativos en el medio ambiente acuático

PBDEs – retardantes de llama bromados

PBDEs son sustancias químicas que se agregaron a plásticos y productos de espuma para hacer más difícil que ardan. Estas sustancias no son compuestos individuales sino mezclas de varias sustancias bromadas. La familia entera consiste de 209 posibles sustancias llamadas congéneres.

Existían tres mezclas comerciales importantes de PBDEs: pentabromodifenil éter (pentaBDE), principalmente en espumas para relleno de tapices de muebles, octabromodifenil éter (octaBDE), principalmente en plásticos de artículos de oficina, por ejemplo computadores, y decabromodifenil éter (decaBDE), principalmente en cubiertas de artículos electrónicos, por ejemplo televisores.

Son prohibidos por la convención de Estocolmo. Son muy persistentes en el medio ambiente.

Efectos en la salud: asociado con defectos del desarrollo neurológico, incluido el deterioro de la capacidad intelectual, el deterioro de las funciones motoras, el aumento de la impulsividad, la disminución de la atención y el daño del ADN, especialmente entre los niños. Entre los adultos, los PBDE se asocian con alteraciones y trastornos de la tiroides, alteraciones endocrinas e irregularidades menstruales y toxicidad cerebral. Posible carcinógeno, particularmente del hígado.

Nombre	# ng/g	Nombre	# ng/g	Nombre	# ng/g
pTBX	0	BDE-140		BDE-207	0
BDE-28	0	BDE-166	0,09	BDE-206	0
BDE-47	0	TBE	0	BDE-209	1,29
BDE-77	1,03	syn-DP	0	DBDPE	0,79
BDE-99	1,42	BDE-201	0,17		
BDE-85	9,06	anti-DP	0		

BDE-154+BB-153	0	BDE-197	0,22		
BDE-153		BDE-208	0		

Figure 2: Example of an individualized report of pesticide and PBD concentrations.

Photos from the Field

Figure 3. What remains of the train system that is no longer in use in Rio Frio, Sarapiquí.

Figure 4. A monument tin Limón that highlights the complex history of the region and its involvement with banana, immigration, and U.S. business owners.

Figure 5. Examples of pesticides being sold for agricultural purposes in Sarapiquí.

Figure 6. Pesticide mixes being sold in Sarapiquí.

Figure 6. Driving through one of the many banana plantations in Sarapiquí on the way to a rural community. The blue bags wrapped around the fruit are insecticide bags.

Figure 7. A pasture in Sarapiquí

Photos of Laboratory Procedures

Figure 8. On the left is a photo of the extraction process and the photo on the right represents the dilution process.

Figure 9. The photo on the left shows the cleaning process of the extractions and the photo on the right is of the final vials being readied for mass spectrometry.

CURRICULUM VITA

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CURRENT POSITION:

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2023-2024 Editorial Associate
Chiricú Journal: Latina/o Literatures, Arts, and Cultures

2023-2024 Research Consultant
Indiana University and Felege Hiywot Center
RISE Initiative

2018-2023 Associate Instructor / Research Scientist
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EDUCATION

2024 Ph.D., Biological Anthropology; Outside Minor: Food & Nutrition Policy
Indiana University, Bloomington, IN

2018 M.A., Applied Anthropology
University of South Florida, Tampa, Florida

2012 B.A., Journalism; Outside Area Major: Anthropology
Indiana University, Bloomington, IN

RESEARCH INTERESTS & SPECIALIZATIONS

Research Interests: Through the combination of socioecological and evolutionary frameworks, I use a biocultural approach to explore the ways in which environments impact biology, including health and well-being, with foci in the social, political, economic, and ecological contributions to growth, development, diet, nutritional status, and health. Explicitly, I am interested in the roles of policy, food systems, (agri)cultural practices, and inequality within human biological and cultural variation, bridging biological anthropology and the fields of food studies, environmental health, environmental endocrinology, and public health.

Specializations: bioanthropology, human biology, anthropology of food & nutrition, food (in)security, food policy, agroecology, endocrinology, diet, nutrition, growth & development, puberty, adolescence, life history theory, endocrine disruption, Costa Rica, United States, rural studies

METHODOLOGICAL COMPETENCIES & SKILLS

Quantitative: advanced statistical analyses (R, STATA, SPSS, Excel), GIS, mass spectrometry + gas/liquid chromatography, survey, diet & nutritional analyses, anthropometry, metabolic and cardiovascular health measures, passive sampling for chemical exposures (wristbands, air samplers), large datasets (e.g., NHANES), data management, data visualization

Qualitative: photovoice, interview, ethnography, journaling/creative writing, pile-sorting, focus groups, coding, NVivo

Science communication: journalism, public relations, blog writing, marketing, graphic design, editing, website design, community-engaged work, community forums, policy recommendations/briefings

Others: community participatory research, applied research, teaching at various educational levels in & outside of the classroom, Spanish fluency

CURRENT ACADEMIC AND PROFESSIONAL AFFILIATIONS

- American Anthropological Association
- Society for the Anthropology of Food & Nutrition
- Human Biology Association
- Indiana University Food and Agrarian Systems
- Indiana University Sustainable Food Systems Science

RESEARCH

GRANTS, FELLOWSHIPS, AWARDS

FUNDED RESEARCH GRANTS

2024 Indiana University Grant-in-Aid of Doctoral Research Award ($1,000)
2023 Indiana University Grant-in-Aid of Doctoral Research Award ($1,000)
2021 National Science Foundation Biological Anthropology Doctoral Dissertation Research Improvement Grant ($16,000)
2021 Wenner-Gren Foundation Doctoral Dissertation Fieldwork Grant ($14,000)
2020 Organization of Tropical Studies Pilot Research Grant ($1,000)
2020 Center for Rural Engagement Lily Foundation Grant: Teen food insecurity in Southern Indiana ($33,000)
2019 Center for Rural Engagement Lily Foundation Grant: Food provisioning among older adults in Indiana Uplands ($237,700)

IN-PROCESS/UNDER REVIEW RESEARCH GRANTS

2023 Inter-American Foundation Community Development Grant: *Cultivando comida, comunidad, cultura, y capacidad*: Youth Agroecological Education and School Gardening Project. Sarapiquí, Costa Rica ($400,000)

FELLOWSHIPS

2022 Organization of Tropical Studies Graduate Research Fellowship
2021 College of Arts and Sciences Dissertation Research Fellowship
2020 Indiana University Department of Anthropology Skomp Feasibility Fellowship
2019 Indiana University Department of Anthropology Skomp Feasibility Fellowship

AWARDS

2023 Graduate & Professional Student Government Fall Travel Award, Indiana University
2023 Outstanding Advanced Anthropology Student Scholarship, Indiana University
2022 Graduate & Professional Student Government Spring Travel Award, Indiana University
2022 College of Arts and Sciences Fall Travel Award, Indiana University
2022 Thomas Marchione Food-as-a-Human-Right Award, SAFN & American Anthropological Association
2020 Human Biology Association Student Travel Award
2019 Del Jones Travel Award, Society for Applied Anthropology

PEER-REVIEWED ARTICLES

Forthcoming

[16] **Howe (formerly Burris), M**., Romanak, K., Xia, C., Wiley, A., Venier, M., (2024). Silicone wristbands: a noninvasive method for measuring chemical exposure for human biology research. *In preparation to be submitted (with invitation) to the American Journal of Human Biology*

[15] **Howe (formerly Burris), M**., Brenes Alvarado, G., Romanak, K., Xia, C., Wiley, A., Venier, M., (2024). Pesticides and Puberty: Assessing the associations between exposure to current-use and legacy pesticides and the timing of puberty among girls in rural Costa Rica. *In preparation*

[14] **Howe (formerly Burris), M**., Brenes Alvarado, G., Romanak, K., Xia, C., Wiley, A., Wasserman, M., Venier, M., (2024). Exploring the determinants of exposure to current-use- and legacy pesticides in a rural agricultural region of Costa Rica. *In preparation*

Under Review

[13] **Howe (formerly Burris), M**., Robinson, J.M., (2024). A Multidimensional Study of Positive Psychosocial Outcomes Associated with Participation in an Urban Agricultural Education Program. *Submitted and under second-round review: Journal of Agriculture, Food Systems, and Community Development (2024)*

[12] **Howe (formerly Burris), M**., Brenes Alvarado, G., Salazar Bravo, G., Wiley, A. Food insecurity across different social-ecological environments and its impact on diet and nutrition among girls in rural Costa Rica. *Submitted and under second-round review: Scientific Reports (2024)*

2024

[11] **Howe Burris, M**. Palde, L.P.R., Leuthart, K.R. *et al.* (2024). Is parity pricing enough? A critical analysis of parity pricing and the case for additional strategies. *npj Sustain. Agric.* **2**, 11 (2024). https://doi.org/10.1038/s44264-024-00017-1

2022

[10] **Burris, M**., Giroux, S.; Waldman, K.; DeBruicker Valliant, J.; Babb, A.; Czebotar, K.; Fobi, D.; Stafford, P.; Knudsen, D.C. (2022). The Interactions of Food Security, Health, and Loneliness among Rural Older Adults before and after the Onset of COVID-19. *Nutrients* **2022**, *14*, 5076. https://doi.org/10.3390/nu14235076

[9] **Burris, M.**, Caceres E, Chester EM, Hicks KA, McDade TW, Sikkink L, Spielvogel H, Thornburg J, Vitzthum VJ. (2022). Socioeconomic impacts on Andean adolescents' growth: Variation between households, between communities and over time. *Evol Med Public Health*. 2022 Aug 22;10(1):409-428. doi: 10.1093/emph/eoac033. PMID: 36090675; PMCID: PMC9454678.

[8] Giroux, S., Waldman, K., **Burris, M.**, Valliant, J.C.D., Babb, A.M., Stafford, P., Fobi, D., Czebotar, K., Knudsnen, D.C. (2022). Food security and well-being among older, rural Americans before and during the COVID-19 pandemic. PLOS ONE. https://doi.org/10.1371/journal.pone.0274020

2021

[7] **Burris, M.** & Wiley, A. (2021). Marginal Food Security Predicts Earlier Age at Menarche Among Girls from the 2009-2014 National Health and Nutrition Examination Surveys. *Journal of Pediatric and Adolescent Gynecology*. 34(4):462-470. doi: 10.1016/j.jpag.2021.03.010

[6] Valliant, J. C. D., **Burris, M. E.**, Czebotar, K., Stafford, P. B., Giroux, S. A., Babb, A., … Knudsen, D. C. (2021). Navigating Food Insecurity as a Rural Older Adult: The Importance of Congregate Meal Sites, Social Networks and Transportation Services. *Journal of Hunger & Environmental Nutrition*, 1–22. https://doi.org/10.1080/19320248.2021.1977208

[5] Robinson, J., Mzali, L., Knudsen, D., Farmer, J., Spiewak, R., Suttles, S., **Burris, M**….Babb, A. (2021). Food after the COVID-19 Pandemic and the Case for Change Posed by Alternative Food: A Case Study of the American Midwest. *Global Sustainability,* 1-17. doi:10.1017/sus.2021.5

2020

[4] **Burris, M.,** Miller, E., Romero-Daza, N., Himmelgreen, D. (2020). Food insecurity and age at menarche in Tampa Bay, Florida. in *Ecology of Food and Nutrition*. https://doi.org/10.1080/03670244.2020.1727464

[3] **Burris, M.,** Bradley, S., Rykiel, K., Himmelgreen, D. (2020) Teen Food Insecurity: Finding Solutions through the Voices of Teens. in *Human Organization.* 79:1.

2019

[2] **Burris, M**., L. Kihlström, K. Serrano Arce, J. Dobbins, E. McGrath, A. Renda, T. Cordier, Y. Song, K. Prendergast, E. Shannon & D. Himmelgreen. (2019). Food Insecurity, Loneliness, and Social Support among Older Adults. *Journal of Hunger and Environmental Nutrition.* https://doi.org/10.1080/19320248.2019.1595253

[1] L. Kihlström, **M. Burris**, J. Dobbins, E. McGrath, A. Renda, T. Cordier, Y. Song, K. Prendergast, K. Serrano Arce, E. Shannon & D. Himmelgreen (2019) Food Insecurity and Health-Related Quality of Life: A Cross-Sectional Analysis of Older Adults in Florida, U.S., *Ecology of Food and Nutrition*, 58:1, 45-65, doi:10.1080/03670244.2018.1559160

PRESENTATIONS AT PROFESSIONAL MEETINGS & CONFERENCES

2024 **Burris, M**. & Robinson, J. Proximate and long-term benefits of urban youth-led agriculture: a case study from Indianapolis, Indiana. *2024 American Anthropological Association Annual Meetings*, Tampa, Florida

2024 **Burris, M**. Spatial inequalities in food insecurity prevalence and diet among youth within a rural agricultural region of Costa Rica. *2024 AFHVS-ASFS Conference: Right to Food-Food as Commons*, Syracuse, New York

2023 **Burris, M**. & Brenes Alvarado, G. The Juxtaposition of Agricultural Landscapes and Food Insecurity in Sarapiquí, Costa Rica. VII *Wallace Scientific Conference*, Turrialba, Costa Rica

2023 **Burris, M**. & Wiley, A. Rural life, pesticide exposure, and puberty: A preliminary analysis of the relationship between industrial agriculture and pubertal timing among girls in Sarapiqui, Costa Rica. *Human Biology Association Annual Meeting*, Reno, Nevada

2021 **Burris, M**. & DiMarco, M. Teen Food Insecurity: A Case Study from Rural Indiana. *American Anthropological Association Annual Meeting*, Baltimore, Maryland

2021 **Burris, M**. & Vitzthum, V. Evaluating the impact of urbanization on child growth in an indigenous Bolivian high-altitude population. *Human Biology Association Annual Meeting*, virtual

2021 **Burris M**. & DiMarco, M. Teen Food Insecurity in Southern Indiana. *Indiana University Rural Conference*

2020 **Burris, M.**, Food insecurity, Stress, and Age at Menarche among US Adolescents*. III Seminario de Bioantropología DO GEB/UEPA 2020*, virtual

2019 **Burris, M.**, & Wiley, A. Low household food security associates with earlier mean age at menarche among Girls from NHANES 2009-2014. *Human Biology Association Annual Meeting*, Cleveland, Ohio

2019 **Burris, M.**, Bradley, S., & Himmelgreen, D. Teen Food Insecurity: Finding Solution through the Voice of Teens. *Society for Applied Anthropology Annual Meeting*, Portland, Oregon

2018 **Burris, M.**, & Himmelgreen, D. Food Insecurity Associates with Age of Menarche among Girls in Tampa Bay, FL. *Human Biology Association Annual Meeting*, Austin, Texas

2018 **Burris, M.**, Bradley, S., Rykiel, K., and Himmelgreen, D. Teen Food Insecurity: Finding Solutions through the Voice of Teens. *National Conference on Equitable Development*, 2018, Daytona, Florida

2018 Himmelgreen, D.A., A. Steele, **M. Burris**, J. Dobbins, D. Kleesattel, T. Mantz, E. McGrath, A. Renda, K. Serrano Arce, E. Shannon, and K. Prendergast Towards a Holistic Understanding of Food Insecurity: Linkages between Food Insecurity, Social Isolation, and Loneliness among an Older Adult Population. *Society for Applied Anthropologists Annual Meeting*, Santa Fe, New Mexico.

2017 **Burris, M**. Food Insecurity among Adolescents: A Biocultural Analysis of Pre-teen and Teen girls in Tampa Bay, Florida. *Graduate Association for Food Studies*, 2nd Annual Meeting: Future of Food Studies, St. Louis, Missouri

2017 D.A. Himmelgreen, **M. Burris** and L. Kihlstrom. A critical biocultural perspective on the role of food insecurity on infant and child feeding. Nutrition and Nurture in Infancy Conference, Maternal and Infant Nutrition and Nurture Unit (MAINN), University of Central Lancashire

2017 **Burris, M**. Opening a Can of Worms: The Nutritional Implications of Opening U.S.-Cuba Tourism. *Cuba at the Crossroads Symposium*, Rollins College, Winter Park, Florida

2017 Sweetman, C., & **Burris, M**. Living in Shade; An Assessment of Vitamin D Deficiency in Mother-Infant Dyads Southeastern. *Southeastern Evolutionary Perspectives Society* (SEEPS) 2nd Annual Meeting

2017 **Burris, M**. Food Insecurity and Age of Menarche: Using a Biocultural Approach and Life History Theory to Assess the Embodiment of Food Insecurity Among Adolescents in Tampa Bay, FL. *Human Biology Association 42nd Annual Meeting*, New Orleans, Louisiana.

2016 Himmelgreen, D.A., N. Romero Daza, **M. Burris**. A Critical Biocultural Study of Intra-Household Food Insecurity in Rural Costa Rica. American Anthropological Association, 115th Annual Meeting, Minneapolis, MN

INVITED PRESENTATIONS

2024	Pesticide exposure across social-ecological contexts in Sarapiquí, Costa Rica: a case study among girls. *Indiana University Department of Anthropology Spring Colloquium Series,* January 22, 2024
2023	A preliminary analysis of the relationship between industrial agriculture, development, and food security in Sarapiquí, Costa Rica. *La Selva Biological Station, Organization for Tropical Studies*, May 29, 2023
2023	Food Insecurity Among Immigrant Populations: Challenges, Needs, and Initiatives for U.S. and Indiana Communities, *Immigrant Welcome Center*, April 15, 2023
2022	Investigating the impacts of industrial agriculture in rural Costa Rica. *Critical Food Studies Lab*, November 16, 2022
2022	Investigating the Relationship Between Pesticide Exposure and The Timing of Puberty in Sarapiquí, Costa Rica. *La Selva Biological Station, Organization for Tropical Studies*, May 30, 2022
2018	Teen Food Insecurity in Pinellas County. *Juvenile Welfare Board Meeting*, March 2018
2017	Reconsidering Access: Identifying Gaps in Food Assistance Services. *Summit to End Hunger, National Conference*, Tampa, Florida
2017	Effects of Food Insecurity on Health throughout the Life Course: Breaking the Vicious Cycle. *Summit to End Hunger, National Conference*, Tampa Bay Network to End Hunger
2017	The 'Last Mile' of Food Pantry Food. Technical Report Presentation, *Feeding Tampa Bay*, Tampa, FL
2016	Physical Activity in the Monteverde Zone: An Anthropological Assessment of the Monteverde in Movement Project. *Instituto de Monteverde*, Monteverde, Costa Rica
2016	Local Food Production in the Monteverde Zone: An Anthropological Assessment of the Cajón Project. *Instituto de Monteverde*, Monteverde, Costa Rica

RESEARCH POSITIONS

2024 -	Research Associate II, Urban Institute, UNC Charlotte, Charlotte, North Carolina
2023 - 2024	Researcher/consultant, Indiana University and Felege Hiywot Center, Rise Initiative, Indianapolis, Indiana
2018 - 2023	Researcher, Indiana University Food Institute, Bloomington, Indiana
2017 – 2018	Research Assistant, Hunger Action Alliance, Tampa, Florida
2015 – 2018	Graduate Research Assistant, Department of Anthropology, University of South Florida
2016	Research Intern, Monteverde Institute, Monteverde, Costa Rica

FIELD WORK EXPERIENCE

Costa Rica: Monteverde, San Luis, Santa Elena, cantón de Sarapiquí (Sarapiquí county), Huetar Norte
Region Florida: Tampa, St. Petersburg, Clearwater, Bradenton, Plant City, Lakeland
Indiana: Monroe, Green, Crawford, Lawrence Counties, Indianapolis (Marian County)
North Carolina: Charlotte and Mecklenburg County

RESEARCH PROJECTS

URBAN INSTITUTE, UNC CHARLOTTE

2024 Benefits CLIFF Pilot Evaluation (PI)
2024 Alternatives to Violence Program Evaluation (Charlotte)(Co-PI)
2024 Women & Girls Research Alliance Leadership Café Evaluation, Impact of Social Media (Support)

DOCTORAL DISSERTATION

2022-2023 Investigating the relationship between rural environments characterized by industrial agriculture and the timing of puberty. Funding by NSF & Wenner-Gren Foundation ($30,000)
2019-2022 Feasibility research, Costa Rica. Funding by IU SKOMP feasibility fellowship ($6,000)

INDIANA UNIVERSITY DEPT. OF ANTHROPOLOGY

2024 Comparing pesticide exposure among various passive sampling field methods (in collaboration with the PEEL and Hites Labs)
2024 Silicone wristbands for measuring current-use pesticides and legacy pesticides (in collaboration with the Hites environmental chemistry lab)
2023- The Rise Initiative-- Assessing the value of the Felege Hiywot Center's summer STEAM youth farm program. Funding by the Lily Endowment.
2021 Body Size and Composition, Allostatic Load, and Menarche among Kumara Adolescents
2020 Teen Food Insecurity in Southern Indiana. Funding by the IU Center for Rural Engagement ($33,000)
2019 Food Insecurity Predicts Earlier Age at Menarche Among Girls from NHANES 2009-2014

INDIANA FOOD INSTITUTE

2022 Parity Pricing & Fair Wages for Farmers
2019 Complex Food Provisioning Strategies and Food Insecurity among Low-Income Older Americans. Funding by the IU Center for Rural Engagement

HUNGER ACTION ALLIANCE

2018 Teen Food Insecurity in Pinellas County, Florida. Funding by the Hunger Action Alliance and the Juvenile Welfare Board of Pinellas County
2017 Factors Affecting Health in Older Adults. Funding by Humana Inc.
2017 "The Last Mile" Project. Funding by Feeding Tampa Bay
2016 Food Insecurity and Social Isolation among Older Adults

MASTER'S THESIS

2017 Food Insecurity and Age of Menarche. Funding by the USF department of Anthropology & Feeding Tampa Bay

UNIVERSITY OF SOUTH FLORIDA DEPARTMENT OF ANTHROPOLOGY (GRADUATE RESEARCH ASSISTANT WORK)

2017 Food Insecurity and Infant and Child Feeding Practices
2016 Data Analysis: A Critical Biocultural Study of Intra-Household Food Insecurity in Rural Costa Rica; Literature Review: *Sexual Transmission of Zika in Costa Rica;* Literature Review: *Using Critical Medical Theory to Understand Fertility in Costa Rica;*
2015 Literature Review: *Food Insecurity and Social Experiences among Nicaraguan Migrants in Costa Rica*

MONTEVERDE INSTITUTE (INTERNSHIP RESEARCH)

2016 *Local Food Production in the Monteverde Zone: An Anthropological Evaluation; Physical Activity in the Monteverde Zone: An Anthropological Assessment of the Monteverde in Movement Project*

TEACHING

TEACHING APPOINTMENTS

2018 - 2023	Associate Instructor, Department of Anthropology & Human Biology, Indiana University
2015 – 2017	Teaching Assistant, Department of Anthropology, University of South Florida

COURSES TAUGHT (*INDEPENDENTLY, +ONLINE, #HYBRID)

	SEMESTER	# OF STUDENTS
*ANTH-B260: Biocultural Medical Anthropology	+SP 2023	32
*ANTH-B301: Laboratory in Bioanthropology	#SP 2020, #FA 2020, FA 2022	17 - 21
*ANTH-B200: Introduction to Biological Anthropology	+SU 2022, +SU 2023	22-24
HUB-B200: The Intricate Human (Hunger & Obesity)	#SP 2021, FA 2018	75-100
HUB-B300: Human Dilemmas (Living Downstream)	SP 2019	64
ANT 4740/4930: Language & Social Interaction	SP 2017, FA 2015	22-28

INVITED GUEST LECTURES

Oct. 2019/2021	*Diet and Nutrition,* ANTH-B301, Indiana University
Jan. 2019	*Childhood and Adolescence*, ANTH-B260, Indiana University
March 2018	*Food Insecurity and Age at Menarche;* Nutritional Anthropology, University of South Florida
March 2018	*Quantitative Data Analysis*, Applied Anthropology, University of South Florida
Jan. 2017	*Language and Cultural Values,* ANT 4740, University of South Florida
March 2017	*Language and Advertising*, ANT 4740, University of South Florida
Nov. 2015	*Language Change*, ANT 4930, University of South Florida
Nov. 2015	*Language and Advertising*, ANT 4930, University of South Florida

SERVICE

SERVICE TO THE FIELD/DISCIPLINE

MANUSCRIPT REVIEWER

- Ecology of Food & Nutrition
- Social Currents
- Journal of Hunger and Environmental Nutrition
- Maternal & Child Nutrition
- Children
- Journal of Preventive Medicine
- Journal of Adolescent Health
- BMC Nutrition
- Conflict & Health
- INQUIRY
- BMC Public Health
- Nutrients

Human Biology Association

2020-2022 Student Representative

Designed, organized & co-chaired virtual workshops on job seeking, grant writing for the NSF DRIGG, & network building; Hosted monthly student member virtual happy hours; Organized & co-chaired student breakout session on science communication for the 2021 Annual Meeting; Organized & co-chaired student breakout session on expectations of a thesis/dissertation and the student reception for the 2022 Annual Meeting: Managed the HBA twitter to live tweet on podium presentations at the 2022 Annual Meeting.

Society for the Anthropology of Food & Nutrition

2024 Session Organizer, *Transforming Food Systems: Praxis for Sustainable Agriculture and Social Justice – 2913*, American Anthropological Association Annual Meetings, Tampa
2024 Student Awards Committee Co-Chair
2023 Student Awards Committee

Indiana University

2023-2024 IU Anthropology Graduate Students Association Symposium Planning Committee
2023-2024 IU Anthropology Colloquium Series Committee
2023 IU Food and Agrarian Systems Awards Committee
2023 Invited Panelist for Graduate School Research Day, Putting Together a Grad School Application in the Humanities and Social Sciences
2022-2023 New Faculty Search/Hiring Committee, IU Department of Anthropology
2020 -- Graduate Peer Mentor
Jan. 2022 Invited Interview for IU Food Institute Blog Food@IU https://blogs.iu.edu/foodinstitute/2022/01/31/sfss-member-mecca-burris-plans-to-use- innovative-research-method-for-dissertation-research-in-costa-rica-this-february/
Nov. 2021 Invited Speaker for Professionalization Workshop Series, Department of Anthropology
March 2020 Invited Interview for IU Center For Rural Engagement. https://rural.indiana.edu/news/2020-IUB-mecca-burris.html
Oct. 2019 Volunteer Coordinator for Science Fest, Indiana University
March 2019 Presenter, Anthropology Graduate Student Association Symposium

University of South Florida

2017 – 2018 Marketing Officer, Food Studies Research Initiative, University of South Florida
2015 & 2018 Coordinator & Instructor, Darwin Day, USF Department of Anthropology
2016 – 2017 Communications Officer, Graduate Student Organization, University of South Florida
2017 Graduate Student Q&A Panel, Anthropology Club, University of South Florida
2017 Nutritional Anthropology Workshop Chair and Presenter, Anthropology in Action, USF

COMMUNITY & PUBLIC SERVICE

2022-2024 Natural Helper, Immigrant Welcome Center, Indianapolis, Indiana
2021-2022 Seat C-3, Commission on the Status of Children and Youth, City of Bloomington, Indiana
Project chair: Youth Participatory Budgeting Project; Co-chair: 2021 Teen Round Tables

Technical Reports & Briefs

2023 *(in preparation) Exploring the relationship between industrial agriculture and pubertal timing, food insecurity, and wellbeing in Sarapiqui, Costa Rica.* To be submitted to the Organization for Tropical Studies, the Ministry of Health, and local and national Costa Rican policymakers.
2023 *Felege Hiywot STEAM Farm Camp 2023*, Technical Report. Submitted to the Felege Hiywot Center and Lilly Endowment Inc.
2021 *Portfolio of Findings & Recommendations for proposed White House Conference on Food, Nutrition, Hunger and Health December 2021*. Submitted to the office of Indiana Senator Braun

2021 *Teen Food Insecurity in Southern Indiana*. Sent to school collaborators and Boys & Girls Club

2018 *Teen Food Insecurity in Pinellas County.* Submitted and presented to the Hunger Action Alliance, Feeding Tampa Bay, and the Juvenile Welfare Board of Pinellas County

2017 *Factors Affecting Health among Older Adults.* Submitted and presented to the Hunger Action Alliance and Humana, Inc.

2017 *The Last Mile of Food Pantry Food*. Submitted and presented to the Hunger Action Alliance & Feeding Tampa Bay

SCIENCE COMMUNICATION

2023 Invited guest writer for Public School Works (article publish date: June 2, 2023)

2022 Invited Interview for Associated Press/Report for America (Oct. 2022)

2021 Podcast interview for the Sausage of Science. SoS 126 - *Facing food marginalization with Mecca Burris*. https://podcasts.apple.com/us/podcast/sos-126-facing-food-marginalization- with-mecca-burris/id1340030371?i=1000521122000

2017-2023 Blog writer for The HOTH, St. Petersburg Florida

RESEARCH APPLICATION & BROADER IMPACTS

- Co-design workshops & community forums: I have presented research findings and assisted in the organization and implementation of various community forums and co-design workshops in Florida, Indiana, and Costa Rica. Many of these included policy makers, school nutrition directors, as well as community members.
- Writing and submission of policy recommendations and technical reports
- Writing and publication of press releases
- Creation of individual data reports for participants to educate them on their pesticide exposure, and nutritional status
- Working with schools in Costa Rica to create K-12 curriculum based on dissertation findings
- Training and mentoring of female research assistants in human biology, fieldwork, and anthropology
- Training and mentoring lab assistant, environmental chemistry

VOLUNTEER WORK

- English teaching, Sarapiquí, Costa Rica
- Summer youth farm program volunteer, Felege Hiywot Center
- Natural Helper, Immigration Welcome Center, Indianapolis, IN
- Organization of Tropical Studies: courses, activities, and mentoring
- Wheeler Mission, Bloomington, IN
- Indiana University Campus Farm & Hilltop Garden
- Crimson Cupboard
- Dance instructor, Turning Out Dance Company, Mitchell, IN
- Program volunteer, Lealman and Asian Neighborhood Family Center (2017)
- Feeding Tampa Bay
- Middle Way House Rooftop Garden Project
- Habitat for Humanity Restore
- Hoosier Hills Food Bank