Tea and the Taste of Climate Change

Understanding Impacts of Environmental Variation on Botanical Quality

By Selena Ahmed, PhD

Tea *Camellia sinensis*
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"It has changed. The taste has changed," Aye Ying says after she drinks a mouthful of green *pu-erh* tea, an infusion from the tea plant (*Camellia sinensis*, Theaceae). This plant is the source of all green, white, black, oolong, and pu-erh tea. Aye Ying's words draw me in with confusion and curiosity as I sip the brilliant golden infusion. *It has changed? The taste of tea has changed? How and why is this occurring?* My mind races with questions. *Is this simply a subjective phenomenon? Perhaps Aye Ying's taste buds have changed or her interpretation of the taste sensation related to this tea? Or, if the taste of tea actually has changed, what might this mean for its health properties? Have these possibly changed too? And, if so, what might this mean for the wellbeing of communities that rely on this beverage?*

We are in a village of the Akha socio-linguistic group in the Yunnan province of southwest China, bordering Myanmar. This area is the motherland of the tea plant and encompasses the center of genetic diversity of cultivated tea and its wild relatives. The Akha are one of the indigenous upland socio-linguistic groups that have an extensive history of cultivating tea and managing diverse tea gardens and tea agro-forests. They are members of the Loloish branch of the Tibeto-Burman language family currently populating southwest China as well as parts of Southeast Asia, including Myanmar, Thailand, Vietnam, and Laos. In other words, this area is part of the region where the tea plant originated, and these communities have among the longest history of cultivating tea.

The glorious early-evening sun imparts a glow through the tea infusion, as if to highlight the powerful properties of this healing elixir. The East Asian monsoon has just hit these mountain lands after a long dry season. Its arrival seems to be felt by every bit of life and matter. Leaves, buds, fruit, flowers, and soil are quenched by the rains, their aromas delicately scenting the air. The red clay paths that crisscross the mosaic of forests, fields, paddies, and the village settlement are turned into a slurry of sediment that clings to the shoe soles of all those who enjoy these routes.

Of course, the tea plant is no exception. It also feels the rains after months of dryness. Tea leaves thrive after the first few showers of the East Asian monsoon. They are vibrant with growth. The aroma and taste of tea leaves also are impacted by the rains. This is to what Aye Ying refers regarding the changing taste of tea. Less than a week earlier, I was sharing tea with Aye Ying and her husband, Li Gan, here on their porch overlooking the remarkable tea agro-forests beyond the village settlement. At that time, the main route that runs through the village was bursting with movement as community members returned from the fields and forests with kilos of fresh tea leaves that were ready to fire dry and package for market. Tea traders sipped tea from small porcelain cups and large enamel mugs looking for the best quality leaf they could afford. Now, with the onset of the East Asian monsoon, the local tea economy will shift pace and flavor for the season until the rains retreat.

Li Gan, a leader in this Akha community, tastes the tea and concurs with his wife that, indeed, there is an alteration of taste with the rains. The sensory quality of the tea has declined with a less-intense tasting infusion. "Tea buyers and traders coming to these mountains will be willing to pay less for this tea," Li Gan shares as he holds up the tea infusion to the sun. He is one of the leaders responsible for working with traders and buyers to determine the on-farm tea price here. This price fluctuates seasonally and annually, and ultimately impacts farmers' livelihoods and wellbeing. Li Gan determines the price of the monsoon tea we are drinking to be almost half that of the tea harvested during the spring season. I am amazed at the sensory ability of these smallholder farmers as well as the possibility that the taste of tea can notably change after several heavy rains.

That was eight years ago. Those cups of tea with Aye Ying and Li Gan were the very cups of tea that drove my collaborative research concerning how climate change is impacting tea quality. Since then, I have learned continuously from farmers in southwestern China that tea quality is impacted by the rains as well as numerous other environmental, geographic, and management factors. This led me to develop a large interdisciplinary project with collaborators from Tufts University and the University of Florida — including professors Colin Orians, PhD (chemical ecologist); Tim Griffin, PhD (soil scientist); Albert Robbat, PhD (analytical chemist); Sean Cash, PhD (economist); John Stepp, PhD (cultural anthropologist); and Corene Matyas, PhD (geographer and climate scientist) — on climate effects on tea quality and socio-economic responses. The project is funded by the National Science Foundation's Dynamics of Coupled Natural and Human Systems Program.

Essentially, tea farmers directed my research toward the effects of climate change on their primary source of livelihood, a plant that is intricately tied to their cultural identity and wellbeing. Currently, I am broadening both the geographic and species scope of this project. Most recently, I have started to work to understand the impacts of climate variation on tea growing in the United States, where it is cultivated in diverse microclimates on the island of Hawaii. My conversations with tea farmers have made me realize the importance of understanding the impacts of climate beyond tea; they have made me aware of the need to understand the broad importance of the impact of climate change on the functional quality of botanicals and specialty crops.

In addition to tea, I am assessing the impacts of climate change on the quality, culture, and ecology of sugar maple (*Acer saccharum*, Sapindaceae) resources in the United States and Canada from its northern to southern range. This project is in collaboration with Drs. David Lutz of Dartmouth College, Joshua Rapp of Tufts University, Ryan Huish of Hollins University, and Boris Dufour of Université du Québec.

Functional Quality, Secondary Metabolites, and Human Taste

Functional quality refers to the therapeutic and flavor properties of botanicals that are determined by concentrations of secondary metabolite compounds, also known as phytochemicals.[1,2] Plants produce secondary metabolites for the integral role of defending themselves against environmental stress such as coping with herbivores (including both mammals and insects), high solar radiation, and/or extreme drought. Producing secondary metabolites is costly to plant metabolism; plants will produce high concentrations of these compounds only when they are in some need of defense. Thus, secondary metabolite concentrations of individual plants of a particular botanical species will vary with stress levels resulting from the environmental and management factors under which they grow, coupled with their genetic fate. For example, secondary metabolite concentrations of wild plants can be higher than cultivated plants because of the greater stressors found in a natural, biodiverse ecosystem.*

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Intriguingly, some humans who produce, harvest, and/or consume botanicals have the refined ability to perceive variation in concentrations of secondary metabolite compounds on the basis of their taste and aromatic characteristics.[3] In fact, throughout human history, the sense of taste has been used to identify plants that have toxic and therapeutic properties.[4,5] For example, bitterness of plants often has been associated with therapeutic properties and/or toxicity, thus the distaste for bitter for some individuals can be regarded an adaptation for survival.[6,7] However, researchers have hypothesized that some societies, such as those with intricate subsistence relationships with the environment, may have evolved mechanisms to select plants with bitter, astringent, and unpalatable properties because they associate these tastes with nutritional and pharmacological sources.[8] Ultimately, taste preferences for certain botanicals and processes to transform their taste have become linked with the cultural identity of such communities that consume a relatively high amount of bitter substances in their pharmacopeia and cuisine.

With regard to human health, selecting botanicals with low concentrations of secondary metabolites may have little or no therapeutic effect. Alternatively, consuming high levels of secondary metabolites may be therapeutic; however, for some, consuming such botanicals can be toxic in particular circumstances. Therefore, understanding the factors that impact secondary metabolite levels is beneficial for the optimum production of high-quality botanicals. For tea, quality is largely determined by the concentrations of methylxanthine and polyphenolic secondary metabolite compounds, which are responsible for stimulant, antioxidant, anti-inflammatory, cardioprotective, and other health properties.[9] A wide range of volatile compounds further determines tea quality by imparting rich and complex aromas. Tea's key secondary metabolites for human health can be perceived on the basis of their astringency, bitterness, and sweetness.[3] Some farmers, including smallholder farmers of China's Yunnan province, have traditional ecological knowledge of how characteristics of their tea plants, including secondary metabolites, vary with shade, altitude, slope, plant-insect interactions, and soil type. They use this ecological knowledge to manage their preferences and consumer demand. This ecological knowledge is dynamic and evolves as farmers experiment and share experiences through their social networks.

Farmer Perceptions of Climate Effects on Tea Quality

For obvious reasons, tea farmers who have an extensive cultural history of managing tea gardens are among the

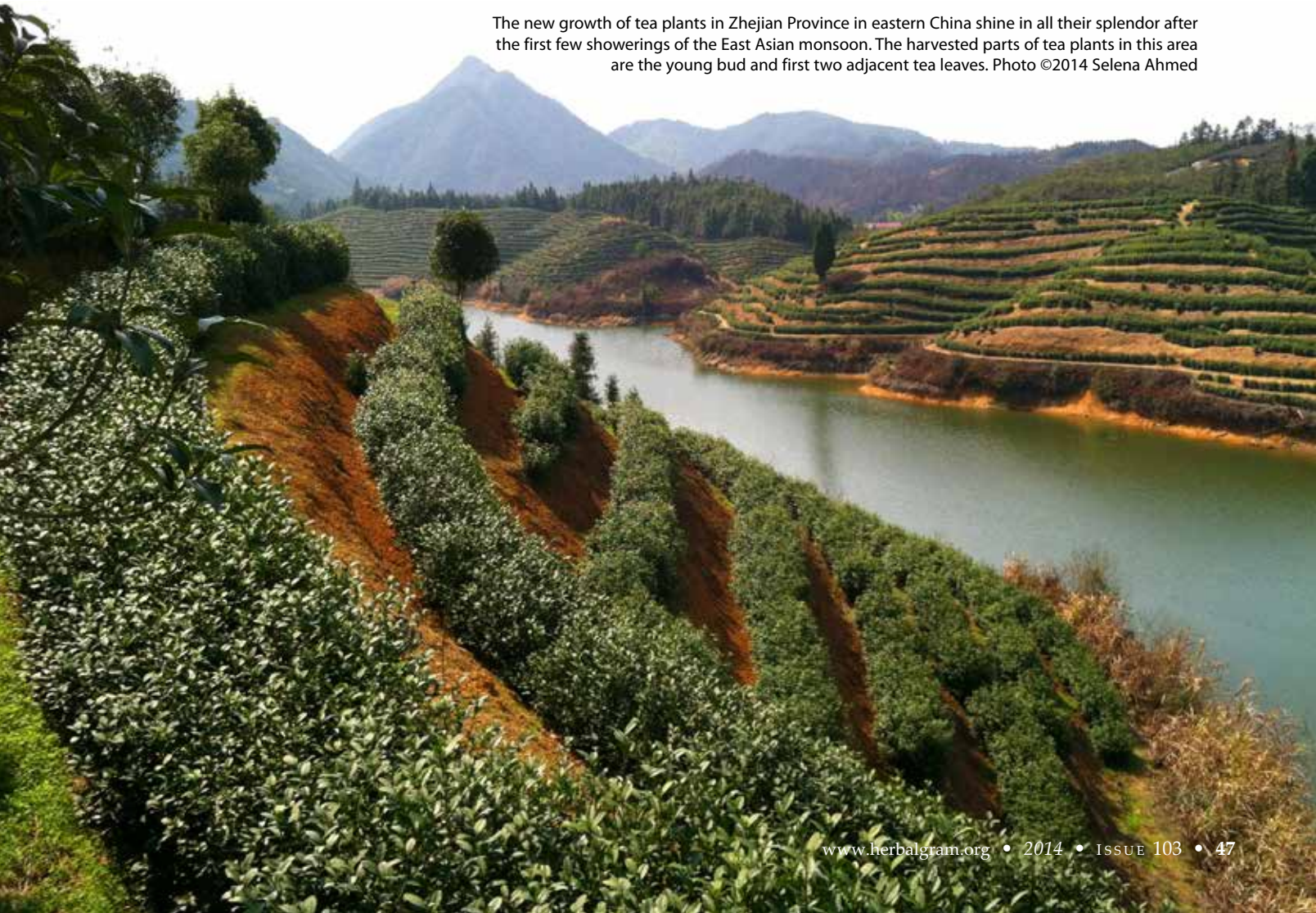
*It is also possible for some food and/or medicinal plant cultivation regimes to organize various agronomic factors (e.g., sunlight, water, etc.) so that the profile of particular desirable and/or undesirable phytochemicals are increased or decreased, depending on the preference of the grower based on commercial interests.

most informed people as it pertains to climate patterns' impact on the yields and quality of tea. As previously noted, farmers I have interviewed in the southern Yunnan province have perceived changing climate patterns and their impact on the yields and quality of tea. The majority of tea farmers I have interviewed state that climate patterns have shifted noticeably over their lifetimes; such observed changes include warmer temperatures, greater unpredictability of weather such as increased variation of rains, and changing phenology of plants (i.e., the effect of weather patterns on plant growth cycles, including flowering and fruiting seasons, etc.), including earlier bud burst.

According to these tea farmers, such weather changes have direct impacts on their tea gardens. Higher temperatures are associated with an earlier tea harvest. Extreme droughts, thought to be more frequent in recent years, are linked to tea leaves that are drier with less budding. Tea harvested during the drought also is purported to have a relatively more intense taste and aroma. Alternately, farmers share that tea harvested during extreme rainy times has beautiful leaves with increased budding, but a relatively diluted taste and aroma. "Tea traders come here for spring tea. The drought this spring has been good for us because the buyers like the tea's strong fragrance and the sweet aftertaste that sticks to the back of the throat (*gaan*). Some buyers tell us they can taste the gaan of this year's spring tea more than one hour after drinking it. The tea we harvest during the rains is not as strong so the price is lower even though we harvest more leaves during the monsoons," Lachu, an elder Akha tea farmer, shares with me.[10]

In addition to the direct impacts of climate change on tea, farmers also need to manage indirect impacts. Warmer temperatures and shifts in rainfall patterns also influence types and quantities of pests and weeds in tea gardens, thus shifting the stress levels of tea plants and thereby their phytochemicals. "We saw more insects this past spring that dried out our tea leaves," Lachu says.

And what do all of these complex environmental interactions mean for farmer livelihoods? Over the past decade, tea farmers at my study sites in southern Yunnan have received up to 50% less income from the tea harvest that follows the onset of the East Asian monsoon compared to tea harvested during the dry spring as the lengths of these seasons shift. It's not just Chinese tea farmers who are experiencing the impacts of climate change in their tea gardens: Tea farmers in tea-producing countries around the world are vulnerable to changing precipitation patterns that have consequences for their livelihoods.[11] For example, a study from almost 20 years ago on Sri Lankan tea production predicted that periods of more intense dryness and rains would damage yields and have negative social and economic consequences for farmers.[12] More recent reports from this year[10] including a news story[13] suggest that climate change threatens the economic viability of Sri Lanka's tea indus-



The new growth of tea plants in Zhejian Province in eastern China shine in all their splendor after the first few showerings of the East Asian monsoon. The harvested parts of tea plants in this area are the young bud and first two adjacent tea leaves. Photo ©2014 Selena Ahmed

try with an increase in pests, volatile weather patterns, rising temperatures, increased competition, and rising labor costs. These factors result in increased costs and consumer prices. However, the story of climate change is not bad news for all. Increasing temperatures during the cold season in parts of the world such as northern India are benefiting farmers with an extended harvest season with an earlier harvest.[14] These differential patterns indicate variable impacts of climate change on tea production on the basis of geographic location.[10]

Effects of Extreme Climate Events on Tea Health Properties

As a field and laboratory scientist, I always find it intriguing to bring back plant samples collected in the field to validate farmer perceptions of medicinal properties in the lab. For the past three years, I have been traveling to China to collect tea samples during the dry spring drought and the heavy monsoon rains. My collaborators and I are assessing these extreme seasonal climate events as a proxy measure to understand climate events that are expected to become more frequent and intense with climate change. We are coupling this sampling in a natural field setting with manipulative greenhouse experiments where we simulate past and forecasted climate patterns to see their effects on tea plants.[15]

My field sampling starts with the collection of harvest units of tea that include the buds and the adjacent two leaves of several tea plants from various tea gardens located in different climate zones and altitudes. I first measure the length and weight of each harvest unit. Next, I process the leaves using a standardized microwave protocol that mimics the processing of green tea in order to deactivate the enzymes that oxidize and degrade tea phytochemicals. This way, the phytochemicals responsible for tea's health properties are preserved. I bring the samples to my laboratory, finely grind up the tea leaves, and extract their phytochemicals in methanol and water using a hydroalcoholic method involving vortexing, sonication, centrifuging, and filtration** that has been optimized to isolate tea's antioxidant and anti-inflammatory compounds. Essentially, I am preparing a product very similar to a high-quality botanical tincture that cannot be consumed by humans because it uses methanol instead of ethanol. I quantify the extracts' key health-promoting compounds, including the widely heralded antioxidant epigallocatechin gallate, using high-performance liquid chromatography. I further measure the antioxidant activity and total phenolic concentrations of these extracts using reagent-based assays. I then share these samples with the Robbat Lab at Tufts University, where researchers analyze the wide range of volatile compounds that gives tea its aroma.

Initial findings from my field and laboratory sampling during the extreme dry and rainy seasons in southern Yunnan show that tea's key health compounds can decrease by up to 50% with

Above photo: Selena Ahmed collecting tea samples in southwestern Yunnan during the East Asian monsoon season to determine the impacts of extreme precipitation events on tea functional quality. After collection, these samples will be measured for height and weight and then processed before they are brought back to her lab at Montana State University to analyze.

Below photo: An elder tea farmer of the Akha socio-linguistic group in southwestern Yunnan sorts dried tea leaves harvested from a tea agro-forest. Photos ©2014 Noah ten Broek

** Vortexing, sonication, centrifuging, and filtration are steps in the preparation of botanical extracts whereby the plant material and the solvent are mixed at high speed in a circular fashion (vortexing) and then soluble plant constituents are extracted by the solvent using ultrasonic waves (sonicating). Non-extractable plant material can be moved towards the bottom of the sample container by gravitational force (centrifuging) and can then be separated from the liquid extract by passing the extract through a material that allows only the liquid to pass (filtration).

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Middle left: A tea master in China's Zhejian showcases a freshly brewed infusion of organic green tea harvested during the spring of 2014 to a group of tea connoisseurs eager to judge its taste and aromatic characteristics during a tea tasting evaluation. Photo ©2014 Selena Ahmed

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the onset of the East Asian monsoon, thus validating farmer perceptions of a decrease in tea quality with the rains. Simultaneously, overall antioxidant capacity and total phenolic concentrations increase, indicating complex changes occurring in the tea plant. In addition, my collaborators at Tufts University have found that the concentrations of some volatile compounds increase while others decrease with the onset of extreme rains. This decrease in tea's main health compounds with the rains is accompanied by an increase in leaf length and weight. It appears that the extreme rains, which are getting more frequent with climate change, may serve to dilute tea phytochemicals and explain the changes that farmers are experiencing.[10]

Farmer Management to Enhance Resilience of Tea Systems

Farmers with an extensive cultural history of managing tea are not only among the most knowledgeable on the subject of climate's impact on tea, but they also possess an ecological knowledge of how to enhance the resilience and adaptation of crop and botanical systems to climate change.[16] While my research has focused on documenting traditional ecological knowledge of tea farmers in China's Yunnan province, I have begun to expand my geographic focus to other tea-producing areas including Japan and Hawaii. Toshiaki Kinesuka, a Japanese tea farmer who has been practicing organic production for the past 38 years in Japan's Shizuoka Prefecture, believes that climate change has not been a major problem for his tea compared to other crops. However, his tea farm has experienced some small climate-driven problems, including increased damage to the spring tea harvest from the increased frost and more unpredictable weather patterns, which makes farming hard to plan. One of the reasons that climate variability may not have had significant negative impacts on his farm may be because of its management practices, which include maintaining soil moisture and microorganisms through organic production; such production also is thought to help control pests.

"Organic tea farming is more resistant to climate change. Non-organic tea farms have had more problems including high and unstable populations of pests," shares Kinesuka. Pests are an emerging issue with climate change as their populations are altered by precipitation and temperature variability. These changes in pest pressures impact the ecological interactions within agro-ecosystems, which can alter secondary metabolite concentrations in plants.[15] Kinesuka regards the forest buffer he maintains around his tea terraces as a living system with insects that are predators to tea pests.

The farmers of tea agro-forests with whom I work in China's Yunnan province would agree regarding the benefits of a forest buffer around tea systems. They believe that tea plants grown in an environment with greater tree canopies and surrounding forests are better able to resist the impacts of climate change. Previous research has documented the numerous benefits of agro-forestry systems,[17] including resilience to climate change,[18,19] maintenance of biodiversity, and higher-quality botanicals.[20]

The ecological knowledge of tea farmers' management strategies for mitigating climate change has led me to examine whether or not tea agro-forests and the phytochemical quality of tea from these systems actually are more resilient to climate change. As I work to identify variables that foster resilience of tea production and sustain farmer livelihoods and consumer wellbeing, I ask myself: "What does climate change mean for the quality and health benefits we derive from our favorite botanicals? And, what ecological knowledge and cultural factors can increase resilience of these natural healing systems that sustain human wellbeing?"

Learning from the ecological knowledge of farmers who have an extensive cultural history of managing indigenous food and botanical systems may be the most promising solution for developing climate change adaptation and mitigation plans.

However, "instead of going back to the past, we need to use traditional farming knowledge for current day. Instead of promoting big agri-business we need to promote producers with heart," suggests Kinesuka before he fades into a deep, contemplative silence.

Promoting smallholder farmers to practice sustainable agriculture such as biodiverse and organic production that

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mimics natural ecosystems is likely to be a promising solution to mitigate climate change in tea systems. This is most likely to occur if smallholder tea farmers are supported in sustainable production through market incentives such as price premiums and fair-trade certification programs. In this way, these farmers can be incentivized to pass on their traditional ecological knowledge to their children and the next generation of tea farmers who will cultivate tea at a time that is forecasted to face increased climate extremes. HG

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