Soil Borne Pathogens and Genetic Host Resistance of Wheat

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I. Acknowledgements

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Çok teşekkür ederim and I look forward to seeing you all again one day

II. Personal Background

I was born and raised in Harlan, Iowa. Growing up in rural Iowa, I was exposed a great deal to the ubiquitous agriculture. Further, having a mother that is an avid gardener, I assisted each summer in the cultivation and harvest of a vegetable garden. My mother came from a farming background, so when we would visit her parents in Wyoming, I was able to see, and to a limited extent participate in, livestock agriculture. In retrospect, however, I feel I took these experiences for granted. I never truly considered the implications of a bad harvest, pestilence, or famine. Living in a region where the soil is so fertile and the food is so plenty blinded me to the possibility.

My father's family is largely medically oriented. My father is a dentist, and his twin brother, a doctor. Two of his sisters are nurses. Their father was a prominent physician in my home town many years ago. Resultantly, growing up, my career exposure was mostly to this end. Initially, I had wanted to be a veterinarian, but after developing allergies to most furred animals, I knew this was out of the question. In the third grade, in a conversation with my mother on the way to a shopping mall, I remember finally deciding I was going to be a doctor. Although the decision was made a long time ago, I have not once reconsidered. I would have never guessed I would one day be researching agriculture in Turkey, and the profound impact it would have on my future.

I was introduced to the World Food Prize in a casual discussion with my high school's agriculture teacher, Mrs. Elmquist, during study hall. Prompted by an article in the latest issue of National Geographic, she and I were considering the implications of drought on Australian agriculture. She mentioned in passing the World Food Prize and told me she felt it was an ideal opportunity for me. Ever the skeptic, I had my doubts, but I followed up with my English teacher nonetheless. At the time, I did not understand the gravity of that decision.

The fall of my senior year, I was awarded opportunity to attend the Global Youth Institute. As excited as I was, I remained skeptical of its legitimacy. What I found, however, was contrary to any preconception I had entertained about the World Food Prize. At the first luncheon, I was inundated with questions from experts and political figures. I cannot recall another time where I was equally as intimidated and excited. Through the course of events the next couple of days, I was convinced of the prestige of the World Food Prize and motivated more than ever to apply for an opportunity to be a Borlaug Ruan international intern.

Months later, without much confidence, I applied for the internship. A number of stressful months later and countless sprints to the mailbox after school, I was awarded an internship in Ankara, Turkey, at the International Maize and Wheat Improvement Center. I was not aware in those moments I opened the letter how much my life had already changed.

III. International Maize and Wheat Improvement Center

Headquartered in El Batán, Mexico, The International Maize and Wheat Improvement Center (CIMMYT) is an international agricultural research center whose aim is to increase production of maize and wheat systems in order to reduce global poverty and increase food security. Initially a pilot program funded by the Rockefeller Foundation and Mexican government in 1943, CIMMYT has since grown into the international organization of today with ties to over 40 countries.

The late Norman Borlaug, the famed wheat pathologist and Nobel Peace Prize Laureate, began his Green Revolution at CIMMYT. Head of the Wheat Program after the center's establishment, Borlaug and his team began developing varieties of wheat that were shorter, had better yields, performed well at different latitudes, reacted more positively to fertilizers, and perhaps most importantly, were resistant to stem rust. His successes inspired many other scientists to advocate similar methods of research and breeding in other countries. In 1966, to aid in grain production in Southern Asia, CIMMYT was officially established as an international center, and they began sending wheat varieties to Pakistan and India. The successes of Borlaug's wheat in these countries as well as other CIMMYT innovations became the foundation for the Green Revolution worldwide.

In 2005, CIMMYT Turkey observed the 20th anniversary of their collaborative efforts to improve the wheat and farming systems of region. The partnership was further strengthened that year when the Turkish Government (Tarımsal Araştırma Genel Müdürlüğü—TAGEM) joined the Consultative Group on International Agricultural Research (CGIAR) along with CIMMYT, one of its longest standing members. Although at present Turkey is self-sufficient in the production of wheat, the increasing demand for food, on an account of growing population (both domestically and internationally), pushes TCI (Turkey/CIMMYT/ICARDA) to develop stronger lines of wheat with better yields. Graminaceous cereals, especially those of the Triticeae tribe (wheat, barley, rye, triticale, et cetera), are incredibly important sources of nutrition for the worlds populations. In fact, more vegetable protein comes from wheat than any other variety of plant. Further, 40% of food in the world is derived from wheat or corn. In many countries, including Turkey, more than half of the calories in a person's diet come from wheat. Moreover, statistical projections suggest that within the next ten years, we would need to see over a 50% increase in the production of wheat to accommodate the growing demand for food. In short, Turkey and CIMMYT as a whole have a great deal of work before them but continue to make great strides in the innovation of agriculture ("Who We Are").

IV. Research

A. Soil Borne Pathogen Research

An Introduction to Cereal Cyst Nematodes

Cereal Cyst Nematodes are of significant economic importance to countries like Turkey where bread wheat is often a dietary staple. Control of this pathogen improves both crop production and income for farmers.

Male *Heterodera filipjevi*
(Photo Credit: A. Markham)

Within the past few decades, Cereal Cyst Nematodes (or CCN) have been identified as one of the greatest causes of yield loss in wheat crops, especially with plants under water stress. The three most economically important species of CCN across the world are *Heterodera avenae, H. filipjevi,* and *H. latipons*. Although *H. avenae* is the most ubiquitous around the globe, *H. filipjevi* is the most economically significant to the Central Anatolian Plateau (CAP) of Turkey. In a survey in 2009, results indicated that *H. filipjevi* was present in up to 78% of the areas where wheat is grown (Riley, et al). On the CAP, yield losses due to this species of nematode have been documented at 50%. Despite this newfound economic importance, little is yet known about *H. filipjevi*.

Nematodes

Nematodes, as a whole, are non-segmented roundworms approximately a millimeter in length and around 50μm in diameter. Plant Parasitic Nematodes (like

CCN) are well known as a detriment to crops, but little research is being done on the soil nematodes that are beneficial to the environment.

Nematodes operate on multiple trophic levels within the soil ecosystem, with different species consuming plant matter, algae, bacteria, protozoa, fungi, as well as other nematodes. For this reason, nematodes are actually quite important for good soil quality.

H. filipjevi, the subject of my research at CIMMYT, falls into the first trophic level and is considered 'plant-parasitic.' Thus, it is classified as a root feeder. However, most soil nematode species are not plant parasitic as all (Ingham).

Life Cycle of Cereal Cyst Nematodes

Heterodera filipjevi is classified as monocyclic meaning it completes only a single life cycle in a given year. This same basic cycle is common to all CCN. After hatching from a cyst, juveniles search for and penetrate the root system of a host plant. Their mouth part, called a stylet (Figure 1), pierces the cell wall and feeds on the root, sapping it of energy needed to grow (Figure 2). After they have fed, male nematodes fertilize the females, who begin to produce eggs. The female's body swells, filling with eggs (Figure 3).

Once egg production stops, the female dies and hardens into what is known as a cyst. The juveniles will later hatch and emerge from the cyst after enduring diapause through the cold period.

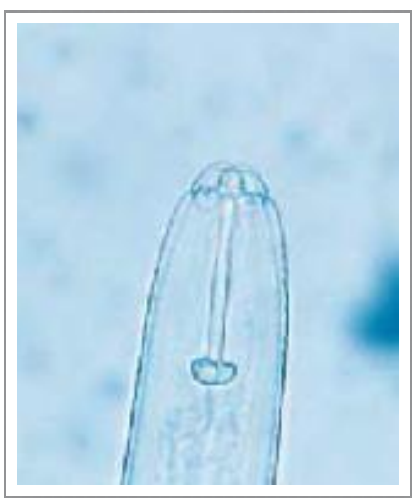

Figure 1: The Stylet of *H. avenae*
(Photo Credit: H. Wallwork)

Figure 2: *H. filipjevi* developing in wheat root
(Photo Credit: H. D. Sağlam)

Figure 3: *H. filipjevi* immature female
(Photo Credit: H. D. Sağlam)

Symptoms

Symptoms of infection from *H. filipjevi* are most visible in seedlings which exhibit yellowing of leaves and reduced tillers. In a field setting, the early symptoms manifest as pale green, uneven patches. These symptoms, however, are easily mistaken for poor nutrition or water stress. Examination under a microscope is the only definitive way to diagnose Cereal Cyst Nematode as the source of infection (Riley, et al).

Control and Management

Many methods are employed to control the populations of CCN in wheat systems. Cultural practices, such as crop rotation with legumes and safflower, have shown to significantly reduce *H. filipjevi* populations. When crop rotation is not possible, practical, or economic, low rates of application of nematicides has shown to be effective in the control of Cereal Cyst Nematodes, but environmental hazards and high costs make this method undesirable. Biological control methods are currently in development that could reduce populations of nematodes through the introduction of natural predators, but they have yet to reach a commercial scale. At present, the preferred method is genetic host resistance, or the use of cultivars with a moderate resistance to *H. filipjevi* (Dababat).

Projects

Although I performed a number of tasks during my stay at ATAEM, I was most involved with two projects in the lab: an attraction experiment and an interaction experiment. The majority of my work concerned *H. filipjevi*.

<u>Attraction Experiment</u>

This experiment was an examination of movement of the nematode species *Heterodera filipjevi* between a cultivar with known moderate resistance and a cultivar with known susceptibility. We suspected that *H. filipjevi* would migrate away from cultivars with confirmed genetic resistance. Experimental units with both pots containing susceptible cultivars should present with roughly equal distribution of nematodes between the two plants. Experimental units with each a susceptible and resistant cultivar should demonstrate a much higher population density of *H. filipjevi* in the root systems of the susceptible cultivar. Finally, experimental units with two cultivars of wheat with marked resistance should present with a roughly equal distribution throughout; however, there should be a disproportionately large amount of male nematodes in these samples.

Methodology

This experiment was conceived based upon an experiment performed by Dr. A. A. Dababat, my advisor, as a part of his Ph.D. thesis. His experiment concerned the movement of nematodes (*Heterodera filipjevi*) in the presences of the fungus *Fusarium culmorum.* Dr. Dababat's experimental system was quite simple: two wheat plants were potted (identical cultivars) with a bridge connecting the soil of the two pots where the plants could be inoculated. Then, as the variable for the test, both, one, or neither of the plants was inoculated with *F. culmorum*. Finally, the bridge between the two plants was inoculated with *H. filipjevi*. After a previously specified amount of time, the experiments were harvested and the movement of the nematodes was determined.

The experiment with which I was involved employed a similar experimental system. Where the variable in Dr. Dababat's trial was the presence or lack of *F. culmorum*, the variable in our new experiment was a resistant or susceptible cultivar. Four breeds of wheat were tested in the experiment. Two known susceptible varieties, namely Bezostaya and Kutluk, were used to contrast two varieties with known moderate resistance, namely Katea and Sömez. Two germinated seeds were sown in each of the pots. The control units were planted with homogenous cultivars in each pot: Katea and Katea, Sönmez and Sönmez, et cetera. The experimental units contained heterogenous species: Katea and Kutluk, Bezostaya and Sönmez, et cetera. After the seeds had sprouted and begun to grow, the bridge between the pots was inoculated with 1 mL of a solution containing approximately three hundred juveniles.

The experiments were then placed in the growth room under controlled conditions ideal for wheat growth (Figure 4). It is not clear whether genetic resistance of a plant to a specific pathogen also affects movement of that pathogen.

At present, these experiments remain in the growth room environment, slated for harvest at a later date. After harvesting the experiments, the root systems and soil will be washed and the number of juvenile, male, and female (both white females and cysts) nematodes will be counted and collected. The resulting populations will be compared to provide an indication of the movements of *H. filipjevi*.

Figure 4: Experiments in Growth Room
(Photo Credit: A. Markham)

My Contribution

This particular experiment over the course of the two months became my undertaking. Initially, I was responsible for the collection of nematode cysts which were incubated and hatched for the juveniles for use in inoculation.

When it came time to begin the actual testing, I was employed to construct the experimental units. My job was to connect the plastic planting pots with via a plastic bridge that could be capped (Figures 5 & 6) I then was tasked to fill the pots and bridge structure with a sand/soil/organic matter mixture and subsequently wet the soil in preparation for sowing. I was then given germinated seeds to plant in the soil. After covering the sown seeds with soil, I placed the experiments in the growth room and monitored their growth for several days. After they had sprouted, I assisted in the inoculation of the bridges, capped the bridges, and returned to the growth room, continuing to monitor their condition until my departure.

<u>Interaction Experiment</u>

This experiment was designed to examine the interaction between two of the primary pathogens researched in the Soil Borne Pathogen Department of ATAEM, *Fusarium culmorum*, a fungus responsible for crown rot in Turkey, and the cereal cyst nematode species *Heterodera filipjevi*. This experiment was performed to determine the effects of the interaction of the two pathogens and identify any correlations between the effects of the two species when combined.

Figure 5: Completed Structure
(Photo Credit: A. Markham)

Figure 6: Set of All Experimental Units
(Photo Credit: A. Markham)

Methodology

This experiment was designed to be performed in a growth room environment where all variables can be controlled. The experiment was conducted on four varieties of wheat: two with noted susceptibility to *H. filipjevi*, namely Bezostaya and Kutluk, and two with a noted moderate resistance to *H. filipjevi,* namely Sönmez and Katea. 24 plants of each variety were used in the experiment (total: 96). Each plant received one of six types of treatment: 1.) No inoculation, 2.) inoculation of only *H. filipjevi*, 3.) inoculation of only *F. culmorum*, 4.) immediate inoculation of *H. filipjevi* and second inoculation of *F. culmorum* three days subsequent, 5.) immediate inoculation of *F. culmorum* and second inoculation of *H. filipjevi* three days subsequent, 6.) immediate inoculation of both *F. culmorum* and *H. filipjevi.* The plants were then placed in the growth chamber and monitored.

This experiment also remains un-harvested. When ready for harvest, the plants will be removed from the growth chamber, the root systems and soil will be washed and juvenile, male, and female (white females and cysts) *H. filipjevi* will be counted and collected. The stems, crowns, and roots of the wheat plants will be analyzed and ranked based upon the extent of infection of *F. culmorum*. The comparison of the two sets of data should reveal a correlation, if one exists, between the severity of both diseases.

My Contribution

I began by assisting Dr. Gül Erginbaş Orakcı in proliferating the fungal spores by culturing *F. culmorum* on wheat germ. Under a fume hood, she sterilely prepared a solution of spores that was added to bags of wheat germ (Figure 7). Over the next several days, I was asked to monitor the growth of the fungus in the incubation chamber.

A number of weeks later, a suspension was prepared using the spores from from the wheat germ. The suspension contained approximately one million spores per mL. I then was employed to inoculate specific wheat plants within the experiment with *F. culmorum* (Figure 8) while another team member inoculated other plants with *H. filipjevi.*

Second inoculation occurred 3 days subsequent to the initial inoculation; however, I was stationed elsewhere when this occurred.

B. International Winter Wheat Improvement Program

The International Winter Wheat Improvement Program is an international collaborative effort between International Maize and Wheat Improvement Center (CIMMYT), International Center for Agricultural Research in the Dry Areas (ICARDA), and the Turkish Ministry of Agriculture (TAGEM) to improve the cultivars of winter wheat for Turkey and surrounding area as well as increasing the global germplasm exchange. Dr. Alex Morgounov, who is also the head of CIMMYT Turkey, leads the IWWIP program.

Figure 7: Preparation of Culture
(Photo Credit: A. Markham)

Figure 8: Inoculation of Wheat with *F. culmorum*
(Photo Credit: A. Markham)

I was afforded the opportunity on a number of occasions to work with Dr. Morgounov and his team with IWWIP program.

My first experiences with the IWWIP program involved negative selection of breeds of wheat with marked susceptibility to disease, namely, *Puccinia sp.*, or rust diseases. This was performed before the wheat had dried *Puccinia* susceptibility was determined by the presence of a fine, yellow dust on the leaves of the plant (Figure 9). Negative selection was performed by breaking the stalks of the wheat plant several inches below the spike to indicate to those making positive selection after the wheat had dried that this particular cross breed of wheat formerly had a marked susceptibility to *Puccinia*. I, along with members of the IWWIP team, walked each row of wheat within the IWWIP nursery and discarded, or negatively selected, each variety or cross breed with susceptibility. This negative selection is performed in the process of cross breeding in order to facilitate artificial selection.

After wheat varieties with susceptibility to rust were discarded, there remained a limited number of cross breeds from which desired traits can be bred. These remaining cross breeds exhibit what is referred to as genetic host resistance, or natural, moderate resistance to a specific pathogen, the current preferred method of controlling many pathogens in graminaceous crops.

Much later in the season, after the wheat had dried, I was again called upon to assist in IWWIP experiments. First, I assisted in the spike harvest. I was employed to label envelopes and, after completion of the envelopes, harvest spikes. The spike harvest is done when a breed of wheat in a nursery demonstrates desirable traits. 50 spikes are harvested from each plot of wheat and are later thrashed, and the seeds are used for proliferation. Each cross breed of wheat demonstrating desirable traits will be replanted the following season on a larger scale to check for genetic variation.

Figure 9: Noted susceptibility to *Puccinia*. Notice the yellow color.
(Photo Credit: Andrew Markham)

I was also asked a few days later to assist in a statistical analysis of the wheat plants. I walked the generation plots, recording peduncle lengths as a number team member measured them with a meter stick. Peduncle length is the distance measured from the bottom of the spike to the first node of the wheat stem. Shorter heights of wheat are more desirable as the plant puts less effort into upward growth and more effort into larger spike size resulting in greater yields.

The few days I spent in the fields with the IWWIP program were immense learning experiences. Dr. Morgounov discussed with me in detail the long breeding process associated with developing and releasing a new breed of wheat. At a minimum, it takes 12 years from the second filial generation to the final cross that it released to the farmers. I learned about the anatomy of wheat as well as assorted afflictions to wheat in Turkey not researched in ATAEM's Soil Borne Pathogens Department including Sunni Pest, loose smut, and blight. I feel my time with IWWIP complemented my experiences with the SBP Department as I was exposed to both approaches to pathogen research: genetic host resistance and soil pathology, or research of the soil pathogens.

VI. Cultural Experience

(Photo Credit: Özlem Korkmaz)

Before the World Food Prize, I cannot recall ever considering traveling to Turkey. Even after I received confirmation of my internship, I merely toyed with the idea, daydreaming during my monotonous high school classes. As my senior year rapidly drew to a close, I was thrust out of high school and had a measly two weeks after graduation to pack and enjoy time with friends and family before departing for Turkey. I suppose that I never really had time to consider what exactly I would be doing over the summer, and I think this lack of preconception truly made my experience what it was. In those last few weeks before I got on my flight, I would never have imagined that over the course of my summer I would fall in love.

I fell in love with the people. I have never before experienced such hospitality. The Turks are kind and genuine as a default. Despite my obviously foreign appearance, I was assimilated into their culture. The people of Turkey are genuinely nice, friendly, and helpful. On one particular occasion I was foolishly struggling to remove a bottle cap from a glass bottle of coke. A young Turk, not much older than I, walked over and without saying a word took the bottle from my hand, took out a set of keys with a bottle opener, removed the cap, handed the bottle to me, and proceeded to go on his way. This simple gesture really surprised me. Looking back, I think that this simple gesture accurately conveys the hospitable spirit of the Turkish population. I also had the opportunity to stay in Ankara with one of my advisors, Didem, and her family. She and her family so graciously opened their home to me, made me feel like family, and prepared amazing meals. In the work environment, I was equally incorporated into the family. The staff at Geçit Kuşağı Tarımsal Araştırma Enstitüsü Müdürlüğü (ATAEM) was warm, helpful, and welcoming. They were more than happy to help me and teach me about agriculture in Turkey. The camaraderie and hospitality I experienced while in Turkey is something I will never forget.

(Photo Credit: Andrew Markham)

I fell in love with the food. I must preface this by explaining that, prior to this experience, I was an incredibly picky eater. I detested when food touched on a plate. I thought vegetables on pizza were disgusting. I would never in my wildest dreams have fathomed eating testicle, kidney, or liver; yet, somehow, Turkey changed that. The wholesome, healthful food that constitutes Turkish cuisine is nothing short of delicious. As a matter of fact, I gained about nine kilos (almost 20 lbs.) over the summer. This, I am sure, is due a great deal to the fact that Turkish culture revolves around food. Although in the States I tended to eat a great deal, in Turkey, I became full much more quickly, so I ate less. Turkish food is much more substantial than many of the foods of an American diet. I was asked repeatedly why I ate so little. They said that for a man, I ate too little. Because of their jibes and because I truly loved the food, I began eating a lot more. I definitely recognized that my eating habits changed. I began eating three portions where I only would have eaten one. We often joked about my goal to gain a 'Türk Balkon,' or Turkish Balcony (a potbelly), during my stay. As my appetite increased, so did my palate. I began eating things I had refused to try in America, eggs, zucchini, eggplant, and mushrooms, and realized I actually liked them. One particular culinary experience in Yozgat demonstrated the extent of my palate: I consumed testicle, kidney, and liver of lamb. Surprisingly enough, they were quite succulent meats, though I would not often eat either liver or testicle. As a result of these newfound dietary habits, I find that my overall diet has changed. I am much more open to trying new things. When I am really hungry, however, I love to prepare that wholesome Turkish food I remember.

I fell in love with the Turkish language. In high school, I was enrolled in the Spanish program. It was in Spanish class that I first recognized my love for languages. Resultantly, I began learning other languages. I first learned Italian then, soon thereafter, French and Arabic. Further, the last semester of high school, I participated in an online intensive Arabic course. When I discovered I would be traveling to Turkey, I was overjoyed at the opportunity to learn and apply new language skills. After taking that intensive course in Arabic, I felt unstoppable when it came to language learning. I couldn't have been more wrong. I have unequivocally never struggled so much to learn something. I simultaneously hated and loved Turkish. On weekends when Didem, an English-speaker, would return to Ankara, I would remain in Eskişehir with other team members who spoke little to no English. This forced immersion demanded that I learn the language, and it could not have been a better experience. After a number of days of pure immersion, something clicked. I suddenly began to understand the spoken and written language better, and I was able to form simple sentences. Within the next few weeks, I was able to order food, purchase movie tickets, convey feelings, and speak in both past tenses and the future tense. Slowly, I built up a vocabulary and became decently conversational. By the end of my experience, I could comprehend much of what was being said to me and could respond in simplistic ways. Although Turkish was the most widely spoken language I encountered, I also had some exposure to Arabic, Russian, Farsi, and Azeri. Upon my return to America, I was shocked to be in a situation where most people spoke English. I still respond in certain situations with Turkish. I have on more than one occasion found myself shaking my head and pleading, "Anlamadım, anlamadım" (I don't understand) with English speakers when I am confused. To this day, months later, I miss the Turkish language. I relish in each opportunity I get to learn and speak it, and I look forward to one day returning to Turkey to apply my newfound language skills.

I fell in love with the land. Despite no preconceptions of what Turkey would look like, I feel I was most shocked by the sheer beauty of the region. Gently rolling hills, green, luscious valleys, spectacular geological formations comprise the Turkish landscape. I never ceased to be amazed by the sheer beauty of the countryside. Working with the land here felt like a privilege. Each day I spent in the field, although performing tiring tasks, I felt refreshed. I truly just enjoyed my time beneath the Turkish sun. The cityscapes were equally as beautiful. Brightly colored, neatly landscaped, and efficiently organized, the cities I lived in, namely Eskişehir and Ankara, prided themselves on aesthetic appeal. Further in Eskişehir, after dark the entire city would light up like Christmas in the States.

Although I was only able to see a small portion of the country and experience a small portion of the culture in my short time in Turkey, I would argue that it was the best way to experience Turkey. Working with bread wheat in a country that places such an emphasis on food allowed me to examine the deep cultural ties people have to the land and to agriculture. I was able to explore a part of their culture quite completely. My two month immersion in the Turkish culture was not remotely enough for me. I greatly anticipate returning to Turkey and experiencing more of what the beautiful country has to offer.

(Photo Credit: Andrew Markham)

(Photo Credit: Andrew Markham)

VII. Conclusion

Throughout the Global Youth Institute, the internship application process, and orientation, I recognized a common idea being expressed: this experience is life changing. Now, I'm not going to pretend like I believed that in the beginning. To be perfectly honest, I'm not sure I believed it through most of my internship. It was not until the plane ride home that I was really forced to reflect on the events of the previous two months. Priding myself on my pragmatism and objectivity, I have never been a very emotional personal; however, on my twelve our flight from İstanbul to Chicago, I remember the most profound feeling of loss. I felt as if I were leaving my family, as if I leaving a part of me, in Turkey.

Since my return to the States, I am daily forced to acknowledge how much of a changed person I am. I notice the simple things. My diet has changed. My music tastes have expanded. I am better able to function with little sleep. But I also notice the more profound changes. I have a renewed perspective. My goals for the future have changed. I am more motivated than ever to pursue a career where I can help people. Although I am not currently pursuing a career in agriculture, agricultural research taught much about people and about life, and these are things I can apply to my career in medicine. Having worked with wheat and the slow process of cultivation and harvest of plants, I find myself more patient. The research in which I participated and the country where I lived taught me about the trials of a struggling world. As the sixth largest wheat producer in the world, Turkey is instrumental in the battle against global hunger due to its proximity to extreme poverty in Northern Africa and the Middle East. Working with CIMMYT taught me that one man cannot carry the weight of the world. Each of us can only do the best we can and as much as we can to help reduce poverty, hunger, and injustice across the world. My many conversations over a microscope or cup of tea taught me a lot about human nature and relationships. These conversations also taught me a lot about myself, my goals, and my future. Finally, as a whole, this experience has further incited my passion for helping people, an immense asset in the field of medicine.

As I continue to pursue my career in medicine, I appreciate the knowledge and skills I obtained on this internship and I cherish the relationships I have made and the lessons I have learned. I now understand what each of the interns before me described as ‘life-changing.’ It is not changing insofar as that I was physically or mentally altered. No, it is change in that this internship contributed to my life in an enduring way, in a way that will remain with me for the rest of my life. For this, I am immensely thankful. My mind often times returns to the issue of hunger. I imagine this is something else that will remain with me. The late Norman Borlaug, through his work, teaches us to be humble and do all that we can to help reduce global hunger and poverty. Because all I have learned, I know that in the future I will do my best to contribute what I can to the improvement of our world.

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