Ethnophytopathology and Survey of Tomato Diseases in Morogoro, Tanzania

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Tomato (*Solanum lycopersicum*) is an important vegetable crop worldwide. In Tanzania, tomato is one of the three most commonly grown vegetables and is produced mainly as a cash crop. Tomato production in Tanzania is performed mainly by smallholder farmers (farmers with land-holdings of less than 2 ha). Tomatoes serve as both a source of income and nutrients for smallholder farmers and their communities.

Yields of tomato in Tanzania lag behind tomato yields in developed nations and other East African nations. Tomato yields in similarly sized nations in East Africa, such as Kenya and Ethiopia, are much higher than Tanzanian tomato yields (UNFAO, 2011). In Tanzania, tomatoes were produced on 30,000 hectares in 2011 with an mean yield of 83,333 Hg/Ha (88). At the same time, the mean yield of tomatoes in the United States was 10 times higher (848,833 Hg/Ha) than mean yield in Tanzania. Since 1961, 21-fold more area is harvested for tomato, production has increased 25-fold, but total tomato yield has only increased 1.2 fold in Tanzania (UNFAO, 2011). In the United States, tomato yield has increased 3-fold since 1961, whereas, in Kenya, tomato yield has increased 1.5-fold.

No single explanation is available for low tomato yields and yield stagnation in Tanzania. Tomato production practices in much of the developed world are technologically driven, with some production done in high tunnels and greenhouses (Heuvelink, 2005). Most tomato

production in Tanzania is done in open fields, with few farmers producing in high tunnels (Heuvelink, 2005). Access to inputs, while easy and less expensive in developed nations, is more difficult in developing countries such as Tanzania. United with a lack of inputs, unproductive soils greatly limit crop production (Chipungahelo and Komba, 2009; Ellis-Jones and Tengberg, 2000; van Bruggen and Semenov, 2000). A lack of access to superior tomato germplasm likely limits yields in this region (Luzi-Kuhupi, et al. 2012). Locally adapted, disease resistant cultivars, with locally desired characteristics, are not widely available in Tanzania (Minja, et al. 2011). Reliable, inexpensive seed sources are needed, because contaminated (Mbega, et al. 2012) and unthrifty seed sources reduce yield from the onset of planting. One of the clearest constraints to Tanzanian tomato production is disease (Maerere, et al. 2010).

Tomatoes in Tanzania are affected by a wide range of pathogens. Bacterial diseases of tomato in Tanzania include tomato wilt (causal agent *Ralstonia solanacearum* (Black and Seal, 1999)), canker (*Clavibacter michiganensis* subsp. *michiganensis* (Black and Seal, 1999)), bacterial speck (*Pseudomonas syringae* pv. *tomato* (Black, et al. 2000; Shenge and Mabagala, 2007, Shenge, et al. 2007)), and bacterial spot (*Xanthomonas euvesicatoria, X. vesicatoria, X. gardneri, X. perforans* and a fifth unclassified *Xanthomonas* species (Shenge, et al., 2007a, 2007b, 2010)). Root-knot nematodes (*Meloidogyne* spp.) were found in a majority of tomato samples in a survey of twelve different regions, with *M. javanica* being the most common nematode on tomato (Nono-Womdim, 2002). Reported fungal diseases (Maerere, et al. 2010) of Tanzanian tomatoes include early blight (*Alternaria solani*) and Septoria leaf spot (*Septoria lycopersici*). Tomato late blight (*Phytophthora infestans*) is also a major problem on tomato in Tanzania (Maerere, et al. 2010; Ojiewo, et al. 2011). It is unclear which diseases contribute the most to tomato yield loss regionally. In order to prioritize limited resources for disease

management, a survey is needed of the most commonly occurring diseases in key tomato producing regions.

Current disease and pest management strategies in the Morogoro region and nearby regions rely heavily on pesticides, mainly fungicides and insecticides (Maerere, et al. 2006 and 2010; Ngowi, et al. 2007). In a survey of pesticide usage in Northern Tanzania (Ngowi, et al. 2007), farmers used improvised tank mixes (33% of respondents) and pesticides for non-target pests, and felt symptoms of pesticide poisoning after application (68% of respondents). More education is needed to reduce misuse of pesticides, but an alternative is to look to disease management strategies that reduce reliance on chemical pesticides. In integrated pest management, chemical pesticides are a control measure to be used sparingly, in favor of cultural, biological, and physical pest control measures. In order to develop these management tactics, an integrated, multi-tactical approach is often needed.

A long term goal of integrated pest management programs is to reduce farmer reliance on chemical pesticides by offering alternative disease management strategies. Before these alternatives can be offered to smallholder tomato farmers, it is necessary to have a better understanding of the most prevalent tomato diseases in the Morogoro Region. To address this gap in our knowledge, we determined the most prevalent tomato diseases in the Morogoro Region through disease surveys and enthnophytopathological (local plant disease knowledge (Bentley, et al. 2009)) activities.

Materials and Methods

Study Sites

This research was conducted in five villages in the Morogoro Region. These villages included Msufini, Mabana, Msongozi, Mlali and Kibagala. Baseline surveys were administered to twenty farmers in each village to determine basic characteristics of the famers and their tomato production practices.

Disease Survey

Disease surveys were conducted during the dry (August 2013) and wet (May 2014) tomato production seasons. Within each village, ten fields were surveyed during each season, and within each field, three two-meter squared plots were surveyed for both disease incidence and severity.

Soil Health Assay

Soil was collected from each disease survey field during the wet season disease survey. Soil samples from a depth of 15 cm were collected from 10 random locations within a field. Sub-samples were pooled and mixed well. For the soil health assay (modified for tomato (Gugino, et al. 2009)), 150 mL of soil was placed in the bottom portion of a 500 mL soda bottle with holes punctured in the bottom for drainage. Tomato 'Moneymaker' seeds were planted in each pot and allowed to grow for 5 weeks, at which time roots were evaluated for root knot nematode galling. Nematode galls were counted and the dry weight for each root was obtained. For each soil sample, there were five replicates and the experiment was conducted twice. Nematode incidence was rated high if galls were present in more than 50% of replicates for a soil, moderate if present 1 - 50% of replicates, and not detected if no galls were found.

Ethnophytopathology Activities

Information on local plant disease knowledge was collected in two activities. For both activities, a set of cards with pictures of key symptoms of 18 tomato diseases, one disorder and one insect pest was used to facilitate farmer discussion. To determine which tomato diseases farmers thought were most important, farmers were asked to identify which five diseases they thought were most important in both tomato production seasons. If farmers selected more than five diseases for either season, responses were discarded. To determine local tomato disease names, farmers were also asked to provide their names in Kiswahili or local language. Names were translated into English and assigned to naming category (symptoms, borrowed, causal agent, weather) according to Bentley et al. (2009).

Results

Farmer Characteristics

The majority of tomato farmers interviewed were male (72%), and the majority of farmers had completed primary school only (81%). The average amount of land under tomato production was 1.67 acres and farmers had an average of 8.9 years of experience producing tomato.

Disease Survey

During the wet and dry seasons, the most commonly encountered tomato diseases included early blight, bacterial spot, Septoria leaf spot, and viral diseases (Fig. 1). During the wet season, tomato yellow leaf curl was the fifth most commonly encountered tomato disease, whereas in the dry season, Botrytis blight was the fifth most commonly encountered disease. Late blight and bacterial wilt are two tomato diseases that can decimate farmers' fields, yet were

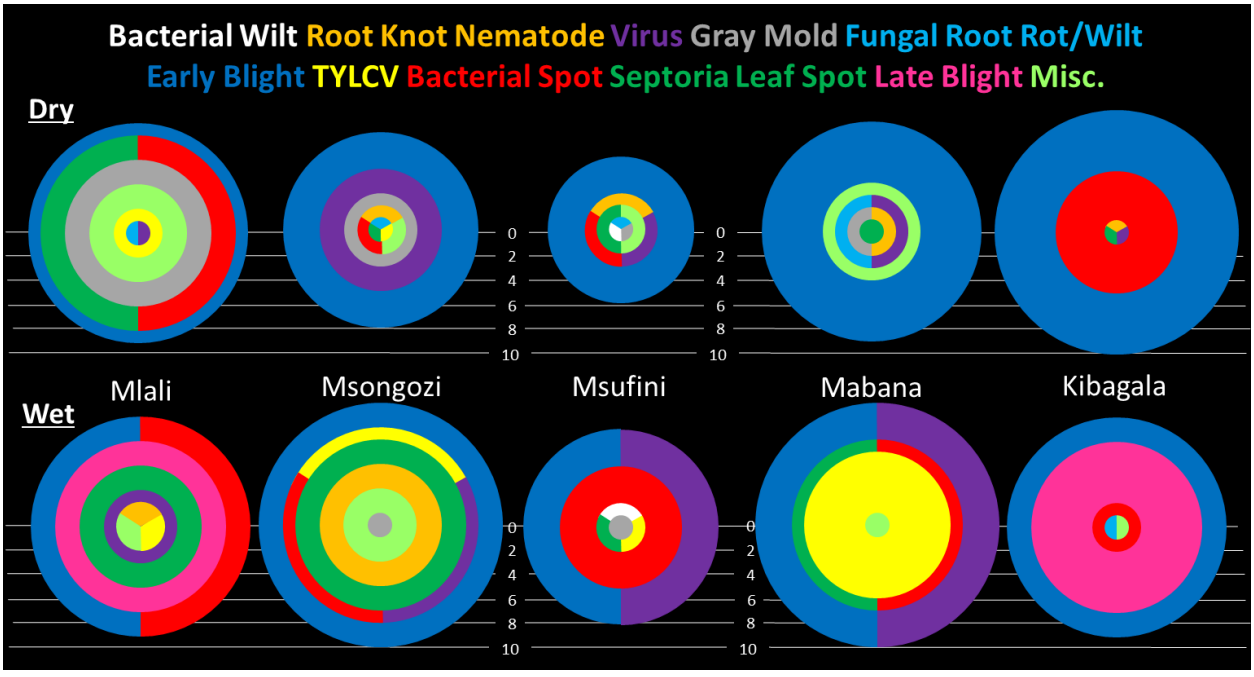
found in few fields during these disease surveys. Late blight was only found in two villages during the wet season and bacterial wilt was only found in one village during both seasons.

Two new tomato diseases were identified in Tanzania during this study. Pith necrosis, caused by *Pseudomonas cichorii*, was identified in Mabana and Msufini (Testen, et al., 2015). Tomato big bud, a phytoplasmal disease, was identified in Msufini, Mabana, and Msongozi.

Soil Health Assay

For the soil health assay, root knot nematodes were detected at high incidences in at least one experiment for 42 of 50 soil samples and at moderate incidence in seven samples. Only two soil samples were apparently free of root knot nematodes.

Figure 1: Incidence of tomato diseases in the Morogoro Region during the dry and wet tomato production seasons. The diameter of each circle indicates the number of fields in which the disease was found in each village (max=10), while circle color indicates which disease was found.



Ethnophytopathology Activities

Farmers ranked four diseases as most important for both the dry and wet tomato production seasons: bacterial spot, tomato yellow leaf curl virus, root knot nematode, and late blight.

Ninety-nine local tomato disease names were gathered from farmers. Farmers most often named diseases based on the symptoms (46% of names) using names such as wilting, lesions, yellowing, and curling. Farmers also named diseases using words borrowed (30% of names) from other aspects of life, such as human health. Examples of borrowed disease names include leprosy, chickenpox, anthrax, camouflage, and ashes. Farmers also named diseases based on the perceived causal agent of the disease (17% of names), but these names were only correctly attributed to the appropriate causal agent for 65% of cases. The final category of local plant disease names were names based on weather conditions associated the disease (5% of names).

Discussion

We took a participatory approach to identify key tomato diseases in the Morogoro Region and develop methods to improve farmer management of these diseases. The approaches we used included disease surveys, soil health assays, and ethnophytopathological studies.

From the disease surveys, we determined which tomato diseases occurred most often in the Morogoro Region. The most commonly encountered diseases (early blight, bacterial spot, Septoria leaf spot, and viral diseases) in our surveys are common tomato diseases globally. Disease identification and management cards for farmer use were created for each commonly encountered tomato disease (Table 1). These cards serve as our main extension output for the project and provide farmers with multiple disease management options. Farmers' reliance on

pesticides could decrease if the farmers use these cards. Pesticide use could decrease for two reasons: farmers better identify diseases, such as bacterial and viral diseases, that would not respond to fungicide use and/or farmers use non-pesticide disease management strategies, such as sanitation or disease resistant varieties.

The soil health assay highlighted the importance of root knot nematode, *Meloidogyne* sp., as a key pathogen of tomatoes in the Morogoro Region. Tropical farmers have few management options for root knot nematodes, but the soil health assay would allow farmers to monitor fields for nematode problems. One potential management strategy for root knot nematode is host resistance. Tomato cultivars could be screened in participatory variety selection trials to determine which cultivars would perform best in nematode infested soils.

Farmer knowledge was incorporated in this study because the participating farmers have extensive experience with tomato production in the region and could identify disease problems that occurred outside of our project period. Farmer identification of late blight as the most important disease of tomato in both production seasons conflicted with our identification of this disease in only two villages in one season. This conflicting information does not indicate that the farmers are wrong, but may be related to weather conditions, the timing of the surveys or other factors. Activities to identify local tomato disease names were conducted mainly to improve farmer-researcher communication in the field. However, these activities also provided interesting insight into how farmers named diseases. For example, farmers in three villages called late blight ‘fulifuli’, a Kiswahili word for cloudy, drizzly weather (the disease conducive conditions for late blight).

In conclusion, this study provided a better understanding of key tomato diseases that constrain tomato production in the Morogoro Region of Tanzania. The findings of this study

form the foundation for developing further projects to support smallholder tomato farmers. Examples of future projects include disease-targeted participatory variety selection trials and tomato disease management workshops for farmers and extension agents.

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Table 1: Descriptors of key tomato diseases and management suggestions developed for use by smallholder tomato farmers in the Morogoro Region of Tanzania

Disease	Basics	Symptoms	Management
Bacterial Spot	This disease is caused by bacteria. It is spread by seed, infected seedlings, rain, splashing water, and plant sap that moves from plant to plant by hands, tools or working in a field. This disease is favored by hot, humid, rainy weather.	On leaves and stems: Small, brown spots that are sometimes surrounded by a yellow color On fruits: Small, brown scabby spots	-Use pathogen-free seeds. If not available, treat seeds with 20% bleach for 1 minute, then rinse well in boiled, then cooled water. Dry seeds in a single layer on paper. -Only transplant healthy seedlings. Transplants should be produced in rows on raised beds. Burn or bury sick seedlings away from the tomato field. -Fungicides will NOT cure this disease. Do not apply fungicides or other pesticides for this disease. -Rotate with maize or paddy to reduce the pathogen in the soil. -Avoid working in fields when leaves are wet. This can spread bacteria. -Space plants further apart to reduce humidity in the leaves. -Remove diseased plant debris from the field. -If diseased weeds are present, remove these weeds from the field. -Water at the base of the plant and avoid splashing water on leaves.
Bacterial Speck	This disease is caused by bacteria. It is spread by seed, infected seedlings, rain, splashing water, and plant sap that moves from plant to plant by hands, tools or working in a field. This disease is favored by cool, rainy, humid conditions.	On leaves: Round, brown-black spots that sometimes have a yellow color surrounding the spots On fruit: Small spots, which may be dark green. Spots are not scabby.	- Use pathogen-free seeds. If not available, treat seeds with 20% bleach for 1 minute, then rinse well in boiled, then cooled water. Dry seeds in a single layer on paper. -Only transplant healthy seedlings. Transplants should be produced in rows on raised beds. Burn or bury sick seedlings away from the tomato field. -Fungicides will NOT cure this disease. Do not apply fungicides or other pesticides for this disease. -Rotate with maize or paddy rice to reduce the pathogen in the soil. -Avoid working in fields when leaves are wet. This can spread bacteria. -Space plants further apart to reduce humidity in the leaves. -Remove diseased plant debris from the field. -If diseased weeds are present, remove these weeds from the field. -Water at the base of the plant and avoid splashing water on leaves.
Bacterial Wilt	This disease is caused by bacteria. The bacteria live in soil and can be spread field to field by tools that have not been cleaned, and in water used for irrigation. This disease can also spread through infected seeds and transplants. This disease is favored by warm, rainy weather that leads to warm, wet soils.	-Young leaves wilt first. -Wilting spreads to rest of plant and leaves begin to die. -Leaves do not discolor before wilting. -Plants wilt unexpectedly and quickly. -The inside of tomato stems are yellow or brown and ooze may be squeezed from cut stems. This is visible in a clear glass of water after a minute or so.	-Do not work in fields with bacterial wilt and then move to disease-free fields. This spreads the bacteria. -Clean tools thoroughly between fields. - Fungicides will NOT cure this disease. Do not apply fungicides or other pesticides for this disease. -Rotate with maize or rice to decrease the pathogen in the soil. -Do not over-irrigate fields harboring the bacteria that cause bacterial wilt and do not allow water from an infected field to spread to other fields.

Disease	Basics	Symptoms	Management
Bacterial Canker	This disease is caused by a bacteria. It is spread by infected seeds and seedlings, and tools or hands that have not been properly cleaned. The disease is favored under warm, rainy, humid conditions.	-Leaf edges become brown and dry. -Leaves may wilt. -Brown, dead areas on stem. -The inside of the stem is light brown. -Dark green spots surrounded by white appear on the fruit.	-Use pathogen-free seeds. If not available, treat seeds with 20% bleach for 1 minute, then rinse well in boiled, then cooled water. Dry seeds in a single layer on paper. -Only transplant health seedlings. Transplants should be produced in rows on raised beds. Burn or bury sick seedlings away from the tomato field. -Fungicides will NOT cure this disease. Do not apply fungicides or other pesticides for this disease. -Rotate with maize or paddy rice to reduce the pathogen in the soil. -Remove weeds from the field that show similar symptoms to tomato. -Rotate with crop that is not tomato, pepper, or African eggplant. -Clean all tools well before moving between plants and between fields. -Water at the base of the plant and avoid splashing water on leaves. -Remove diseased plant debris from the field.
Late Blight	This disease is caused by something that is similar to a fungus. It is spread by wind and rain, and the disease is favored by cool and humid weather.	-Brown patches grow to cover entire leaves, these patches may die and turn a darker color. -On the underside of these lesions, there is white fluffy growth; heavily diseased leaves die. -Large dark brown to black patches may be seen on stems. -On fruits, dark, brown or coppery glossy patches grow to cover the entire fruit. There may be fluffy white growth on these patches.	-Remove infected plant material and infected fruits from the field and burn or bury. -Only transplant healthy tomato seedlings. Transplants should be produced in rows on raised beds. Burn or bury sick seedlings away from the tomato field. -Reduce moisture in the leaves, by spacing plants or watering from the base of the plant. -Remove tomatoes that grow in your fields between seasons as these plants allow the pathogen to survive between seasons. -Some tomato varieties are resistant to late blight and do not develop much disease. -Ask your local extension agent for fungicide suggestions for this disease.
Early Blight and Stem Canker	This disease is caused by a fungus. It is spread by wind and rain, and disease is favored by warm, rainy weather.	-Brown spots form on leaves, fruits and stems. The spots have a bull's eye pattern. -On leaves, the area surrounding the spots turns bright yellow. -Dark brown, oval patches with a bull's eye pattern (cankers) may develop on the stems. -The disease starts at the bottom of plants and moves up. Diseased leaves fall off the plant.	-Bury or destroy all infected plant debris. -Rotate with maize or paddy to reduce disease. -Fertilize plants properly (not to little or too much nitrogen) to reduce early blight. -Reduce humidity on foliage. -Remove weeds with similar symptoms. -Remove tomatoes that grow in fields between seasons as these plants allow the pathogen to survive from one crop to the next. -Ask your local extension agent for fungicide suggestions for this disease.

Disease	Basics	Symptoms	Management
Root Knot Nematode	This disease is caused by very small worms (nematodes). Nematodes live in soils, eating from tomato roots and can also live on other crops and weeds.	-Roots are swollen and have large growths on them. -Roots are not well developed, and there are very few new roots coming from the main root. -Plants with root knot nematodes are smaller than other plants.	-Rotate with maize or paddy to reduce disease. Root knot nematodes cannot eat these plants. -Some tomato varieties are resistant to nematodes. -Manage weeds within the tomato field to reduce nematode food sources. -Only transplant healthy seedlings. Check the seedling roots carefully and don't plant any seedlings with root knots or root growths of any size. -Do not spray with pesticides – pesticides will not control this disease.
Septoria Leaf Spot	This disease is caused by a fungus. The disease is spread by wind and rain. The disease is favored in warm, humid, rainy weather.	-Leaves have light brown spots with dark edges (these spots are usually on older leaves first). -Within the brown spots, there are tiny black spots. -Leaves from very sick plants fall off the plant.	-Rotate with maize or paddy to reduce disease. -Only transplant healthy seedlings. Transplants should be produced in rows on raised beds. Burn or bury sick seedlings away from the tomato field. -Have good weed management practices. -Remove diseased plant debris from the field. -Ask your local extension agent for fungicide suggestions for this disease.
Tomato yellow leaf curl virus	This disease is caused by a virus. The virus is spread by whiteflies.	-Plants are small. -Leaves are discolored and yellow. -Leaves curl upwards and become shriveled. -Leaves may die.	-Fungicides will NOT cure this disease. Do not apply fungicides or other pesticides for this disease. -Do not plant new tomato fields next to fields with mature tomatoes. Whiteflies may carry the virus from the old field to the new field. -Only transplant healthy seedlings. Cover seedlings in the nursery bed with insect-proof netting to prevent whiteflies from carrying the virus to the seedlings. -Monitor crops for whiteflies. -Ask your local extension agent for insecticide suggestions for whiteflies.
Tomato Viruses	These diseases are caused by viruses. They are spread by insects, infected seeds, and plant sap (spread through plant contact or contaminated tools).	-Virus-infected plants are smaller than plants without viruses. -Viruses may cause leaves to be pale yellow or have discolored patches on the leaves. -Virus infected plants may have misshapen leaves or stems.	-Manage insect pests within the tomato field. -Fungicides will NOT cure virus diseases. Do not apply fungicides or other pesticides for this disease. -Clean tools well between plants when working with tomatoes. -Do not work in tobacco fields first then move to tomatoes. A virus that infects tomatoes is very common in tobacco. -Do not smoke tobacco then work with tomato. Wash your hands very well to prevent spreading a virus from tobacco. -Do not plant tomato fields next to tobacco fields. -Washing tools and hands and then dipping then in milk will reduce spread of viruses. -Some tomato varieties have resistance to specific viruses. Ask your local extension agent about these varieties. -Some viruses spread in seeds. Do not save seeds from virus-infected plants.

Disease	Basics	Symptoms	Management
Fusarium Wilt	This disease is caused by a fungus. The fungus lives in the soil and infects the plants through the roots. This disease is favored by warm weather.	-Plant turn yellow and wilt. Sometimes only half of the leaf turns yellow. -Plants may wilt during the day and recover overnight. The inside of the stem has brown discoloration near the soil line. Roots look brown and rotted.	-Rotate with maize or paddy to reduce disease. -Remove excess weeds from the field. -Fertilize plants properly (not to little or too much nitrogen). -There are tomato varieties that are resistant to Fusarium wilt. -Only transplant healthy seedlings.