Harold Hoffmann
Community School of Naples
Naples, FL USA
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Protecting Uganda's Banana Crop: Early Detection of Devastating Diseases

Introduction

Bananas and plantains are the livelihood of East Africa, especially in Uganda, where they provide approximately 30% of the daily calorie intake for 50.7 million Ugandans (Lee, 2023). In Uganda, bananas are more than just food. They are part of the culture and an important financial source to fund a family's home, school fees for children, and medicine for the elderly. In a country where more than a quarter of the population grows bananas as their main crop, it's difficult to imagine a world where such a critical part of daily life is threatened (Uganda Bureau of Statistics [UBOS], 2024). However, this is exactly the case, as diseases such as Banana Xanthomonas Wilt (BXW) cause up to 100% yield losses in weeks (Petsakos et al., 2023). This challenge leads to significant pre-harvest food loss, with infected plants becoming unproductive before harvest and reducing yield. The most concerning part is that by the time a farmer sees the disease on the banana plant, it is often too late to intervene and the infection has spread. Traditional disease management methods such as Single Diseased Stem Removal and farmer training are limited by late detection. Therefore, growers should consider augmenting traditional strategies with novel multimodal sensing methods powered by machine learning to diagnose diseases before they become visible. By acting early, growers will incur reduced costs and produce more food for the community.

Country and Family: Background on Rural Uganda and Matooke Production

Uganda is an East African republic where the average household shelters 4 people on 1.3 hectares of land, roughly the size of two football fields. It remains a predominantly agrarian nation, with 77% of households in rural areas and 62% participating in agriculture, making crop production the backbone of the country's economic security. In fact, 80% of agricultural households grow crops for home use, often keeping 70% of the harvest for home consumption. Families sell surplus bunches in local markets for small but essential cash flow (Lee, 2023). With the median monthly wage from agriculture at just $28, growers possess little financial resilience to absorb widespread crop failures (Uganda Investment Authority [UIA], 2026), which leaves narrow margins for failure since income is irregular and depends on weather and conditions. Threats to crop production therefore don't just reduce yields; they limit both food availability and the income households rely on for basic needs. This puts less food on the grower's table and less cash toward education and healthcare, both recognized as fundamental human rights (United Nations, 1948). This vulnerability is already visible, as 46% of Ugandan households were moderately or severely food insecure (UBOS, 2024).

Because Ugandan homes are typically multigenerational, the entire family helps with farm work, with women and girls primarily caring for the banana gardens, men handling marketing, and children helping after school or during peak seasons (Lee, 2023; UBOS, 2024). Many rural households also lack reliable electricity, clean running water, and all-weather roads, which adds to daily challenges and makes it difficult to scale production (UBOS, 2024). These factors mean that when crops fail, education and healthcare often become too expensive for banana-growing families to afford (UIA, 2026).

Furthermore, the typical diet in rural Ugandan communities is relatively homogenous: starchy matooke (East African Highland Banana) accounts for nearly a third of daily calories in Uganda (Lee, 2023). In

many regions, matooke is consumed daily and in nearly every meal. This concentration around a single crop demands stable growing strategies, as there are few substitutes if production declines.

Challenge and Impact: Banana Diseases Impact Food Loss

Banana crops are severely undermined by pathogens such as BXW, Black Sigatoka, and Banana Bunchy Top Disease (BBTD), killing the plants or lowering their yield.

BXW, caused by the bacterium *Xanthomonas vasicola,* is the most threatening banana disease in Uganda. It infects plants through insects, contaminated tools, or infected water. Bacteria multiply inside the plant and block its vital systems, causing leaves to wilt and fruits to rot, ultimately killing the tree (IITA, 2023). Another disease, Black Sigatoka, caused by the fungus *Pseudocercospora fijiensis*, is Uganda's most widespread banana disease, affecting nearly 95% of farms. While Black Sigatoka is rarely terminal, it reduces a plant's capacity and yields by 30% to 50%, chronically depleting a farmer's annual harvests (Tushemereirwe et al., 2015). Finally, Banana Bunchy Top Disease (BBTD) is a viral infection spread by aphids that causes total reproductive failure. The virus stunts and affects growth, negatively impacting fruit production (Ocimati et al., 2021). Although BBTD is not yet extensively spread, it represents another formidable threat to East African Highland Banana varieties.

These diseases often go undetected until it's too late to intervene and the pathogen has spread to nearby plants. According to a report by Dr. Geberewold (2019), BXW can take up to 16 months to appear in its host, giving bacteria plenty of time to invade neighboring trees. Furthermore, 15-43% of asymptomatic banana seedlings (where infection couldn't be visibly detected), actually were infected with BXW, meaning that growers often unknowingly start and transplant infected seedlings.

The danger of pathogens such as BXW is more than just theoretical. From 2009-2013, a widespread epidemic of BXW caused yield losses of 80-100% in the most severely affected areas, and increased the level of poverty for 85% of banana growers in Uganda (Kankwatsa et al., 2024). This clearly reinforces that if BXW is left uncontrolled, it will result in enormous consequences, estimated by Kankwatsa et al. to cause $25 billion in losses over 10 years. The consequences are not just limited to food security. A study on the impact of BXW control strategies found that uprooting, a control strategy used after late detection, could potentially cause severe soil erosion, threatening a series of additional issues such as increased runoff and natural disasters (Blomme et al., 2019).

Exploring Solutions: Removal Methods, Scaling Training and GMO Introduction

To mitigate the harm of banana diseases, Ugandan communities rely on a combination of removal methods and training solutions.

When diseases hit banana crops, growers have traditionally uprooted the entire field of contaminated trees, using a technique known as Complete Diseased Mat Uprooting (CDMU). Although CDMU effectively removes all infection from the soil, it induces substantial yield losses and soil erosion. In more recent decades, farmers have shifted to the Single Diseased Stem Removal (SDSR) procedure, eliminating individual infected plants, in particular younger seedlings that show any signs of disease. SDSR is much more effective than CDMU, as it is less labor-intensive and results in lower yield-losses. In the field, SDSR was shown to reduce BXW incidence from around 80% to below 2% in just 3-4 months, and below 0.5% in 10 months (Blomme et al., 2019). Additionally, SDSR is a very simple procedure that any farmer can perform without expensive equipment. SDSR's proven efficacy and simplicity makes it the most scalable method to remove BXW in fields.

Farmers must also be well-trained in techniques and strategies to mitigate disease. Actions such as disinfecting tools, cutting male buds, and cleaning all equipment, are simple changes that significantly reduce BXW but require training to implement effectively. Kilkulwe (2020) found that farmers who were trained in BXW management generated 63% more extra value that farmers who implemented strategies but weren't trained. This value increase demonstrates that training significantly boosts the effectiveness of techniques.

Although agricultural training programs already exist in Uganda, the government should restructure those to target women, who manage the daily care of banana plants. Currently, it is mostly men that attend training programs, limiting effectiveness because men traditionally focus on sales. Kikulwe (2020) demonstrated that training women directly increases a household's adoption of crop management strategies. The Ugandan government could design women-inclusive training sessions, distribute BXW control information through communication channels women prefer, and provide diverse educational sources to ensure women receive this critical instruction.

Finally, an emerging solution uses Geneticically Modified Organisms (GMOs) to improve disease resistance. Researchers engineered matooke bananas with the sweet pepper genes *hrap* and *pflp*, which isolate bacterial infections. *In vitro* experiments showed that these genes significantly increased resistance to BXW. During a field trial (Tripathi et al., 2014), most modified plants showed partial resistance, while every single unmodified control plant died from infection. A small number of the modified lines even achieved complete resistance.

A potentially even more exciting innovation is the modifying of plants to better communicate their condition. Persad-Rusell et al. (2022) modified the genetics of potato plants to produce green fluorescence when infected with bacterial pathogens. This fluorescence was detectable with a laser-based scanner from 3 meters away. What's more, George et al. (2026) engineered a bioluminescence resonance energy transfer (BRET) biosensor into Arabidopsis thalian plants. The biosensor emits a certain wavelength when infected with a specific virus. George et al. highlight how these innovations could be effectively used for large scale autonomous monitoring, allowing for labor-free, automated remote sensing.

Overall, these GMO solutions show exciting promise, and may even lead to a future where plants "scream" their problems rather than farmers struggling to diagnose them. However, these technologies can be expensive for smallholder farmers, and corporate seed patents can threaten traditional farming practices. In Uganda, deployment is blocked for these very concerns (Pan African Visions, 2026). Until policymakers balance innovative biotechnology with traditional farming autonomy, these solutions remain infeasible in Uganda.

All in all, existing solutions hold promise to reduce visible disease. However, those solutions fail to address the core issue: the most critical gap in Uganda's banana disease management is not the absence of control strategies, it is the lack of early warning, prior to the emergence of visual symptoms. The nation must invest in new technologies to detect diseases in banana plants using invisible signals.

Recommendation: Development and Deployment of Multimodal Sensing System for Early Disease Detection

Hyperspectral imaging, a visual imagery technique that captures more than 100 wavelengths to extract far greater detail than a standard camera or the human eye, holds great promise for early disease detection. A study by Fajardo et al. (2020) on banana plants infected with Black Sigatoka revealed that diseased plants produce significantly different spectral signatures than healthy plants. A machine learning (ML) classifier detector exploited this difference, and after being trained and tested with presymptomatic leaves, detected

Black Sigatoka with 98% accuracy, showing strong potential for hyperspectral imaging to be used in field conditions.

Furthermore, Volatile Organic Compound (VOC) monitoring picks up microscopic gas particles in the air and correlates them to plant responses. Generally, these chemicals are plant hormones and signaling ligands to communicate or induce stress signals. They have been deeply researched and supported with several crops, such as tomatoes, cucumbers, and maize. Specifically, a study on pine trees discovered that ML models could effectively detect *Fusarium Circinatum* in pine trees still in the asymptomatic stage (Nordstrom et al., 2022). While VOCs have yet to be tested with BXW, Black Sigatoka, or BBTD, successful results in similar plants clearly indicate strong potential for VOCs to be used.

Finally, a recent University of Tel Aviv study discovered that plants produce ultrasonic "clicks" between 20-100 kHz, far above our hearing range, which are produced by mechanical stress and breakage in plant fibers. These clicks were statistically correlated to different types of stress, and a ML classifier successfully distinguished three types of stress (no stress, dehydration, and heat) (Khait et al., 2023). This suggests strong promise for the use of ultrasonic emissions in diagnosis, a completely novel field that is still completely underexplored.

The best solution to detect disease early will be a multimodal sensing system combining several signals such as hyperspectral imaging, volatile organic compound (VOC) monitoring, and ultrasonic emissions detection. Together, these sensors capture different biological signals and feed them into a shared machine learning classifier that flags infection before any visible symptom appears. This compresses BXW's 16-month asymptomatic window into a detection window of days (Geberewold, 2019). Multimodal fusion systems have already demonstrated early-stage disease in several studies, such as in maize, where IoT-connected ultrasonic sensors detected fungal infection four to five days before symptoms appeared on leaves (Maginga et al., 2024), establishing that the approach works against real pathogens in field-adjacent conditions.

Deploying such systems from the research lab to real field conditions will include challenges. Detection accuracy can sometimes drop to 70–85% in environmentally-variable field conditions, and individual hyperspectral systems can cost $20,000–$50,000 (Perumal, 2025). A multimodal sensing system will combat this single sensor limitation. With regards to cost, a 2026 preprint demonstrated a functional hyperspectral camera can be built for under $500, achieving 97.5% binary classification accuracy on presymptomatic infection (Crabb et al., 2026), making such devices accessible. Funding could come from international food security development organizations and Uganda's Ministry of Agriculture, and targeted to specific high-risk regions.

Uganda's existing agricultural extension infrastructure already provides a strong distribution channel, so the system does not require building a new one. Lessons from the scaling of existing training programs must be considered when deploying the novel multi-modal sensing systems. Because women are the primary cultivators, extension outreach must directly target them. Furthermore, sensor outputs must be interpretable without technical literacy, an objective easily achievable with a Machine Learning system connected to a smartphone. In addition to being simple, the interfaces must not only display English and Swahili text, but also local languages such as Luganda and Ruyankitara.

To ensure long-term sustainability and maximize effectiveness, machine learning models should be continuously retrained to adapt to evolving disease patterns and maintain diagnostic accuracy (Perumal, 2025). This creates exciting opportunities for students and faculty in Uganda’s top universities, such as Makerere University, creating a domestic technical base while also educating generations of skilled computer scientists and engineers.

Overall, a successful management strategy requires three pieces: diagnosis, prevention, and removal. A multimodal sensing network combined with SDSR and inclusive training fills these three roles perfectly, with sensors providing early diagnosis, training providing strong prevention strategies, and SDSR providing the best removal technique. By adopting these three solutions together, Ugandan farmers and families will control banana diseases, directly battling food insecurity.

Conclusion

For too long, BXW, Black Sigatoka, and BBTD have moved inconspicuously through the matooke gardens that feed families, pay school fees, and tie rural communities together. The cost of waiting for visible symptoms has already been measured in lost harvests, eroded soils, and deepened food insecurity. However, existing tools transform that story. By pairing Single Diseased Stem Removal with targeted training, especially for the women who tend the plants daily, and deploying low-cost multimodal sensing that catches infection days or weeks before any leaf wilts, farmers can act while diseases are containable. This will produce more food for the family and community, and generate steady cash to fund school fees for children and life-saving medicine.

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