SUPPRESSION OF COFFEE LEAF RUST (HEMILEIA VASTATRIX)WITH THE USE OF TERRA VERA TECHNOLOGY ON BLUE MOUNTAIN COFFEE IN BRANDON HILL, JAMAICA

Jed J. GOODRIDGE[1], Chika J. OZONGWU[2], Machel A. EMANUEL[1], Chinthapalli B. RAO[1], Dwight E. ROBINSON[1] and John LINDO[2]
Department of Life Sciences [1] and Department of Microbiology [2], Faculty of Science and Technology, The University of the West Indies Mona Campus, Kingston 7, Jamaica

ABSTRACT

Coffee Leaf Rust (CLR) caused by *Hemileia vastatrix* has plagued coffee production globally, with an estimated annual crop loss valued at 1-2 billion USD. The Jamaican farmer's choice for CLR control are the highly hazardous chemicals such as Tilt or Opera, which risk consumer/operator health/safety, is a potential environmental hazard and an economic burden on farmers. Terra Vera Technology (TV) serves as a safer alternative to highly hazardous chemicals, utilising a non-toxic, entirely natural formulation. This investigation aims to assess the potential usage of TV, in supressing and reducing the incidence of CLR (*Hemileia vastatrix*) on coffee production of Jamaica Blue Mountain (JBM) coffee located in Brandon Hill, St Andrew, Jamaica. Over the course of nine weeks, plants were evaluated for CLR incidence and assigned to one of four treatment groups: a 2:1 and a 3:1 ratio of reverse osmosis (RO) water to TV, RO water alone, or no treatment. Each group included plants exhibiting a range of disease severities, from Level 0 to Level 7, as determined using a standard area diagram severity chart. Coffee plants treated with TV showed a greater reduction in disease severity compared to the controls. The 2:1 TV solution showed a significant difference ($p < 0.05$) compared to the 3:1 concentration. These results suggest that the 2:1 TV concentration has the potential as an antifungal agent for suppressing CLR disease in coffee production in Brandon Hill, Jamaica. However, a comparative assessment of the application of TV to an acre of coffee plants was estimated to $34,248.38 JMD compared to $18,656.27 for application of Tilt. The initial investment and logistics of TV doesn't support a direct to customer relationship with small farmer holdings.

Keywords: coffee leaf rust; terra vera technology; coffee; Jamaica.

INTROUDCTION

Coffee Leaf Rust (CLR) is a plant pathogen caused by a fungus classified in the phylum Basidiomycota, the class Pucciniomycetes, order Pucciniales (rust fungi) and in genus *Hemileia*. The most significant species is *Hemileia vastatrix*, which is capable of evolution and has produced new virulent races (Koutouleas et al. 2019, 13621). Presently, over fifty *H. vastatrix* physiological races have been identified globally (Sera et al. 2022, 3; Keith et al. 2023, 2528). While CLR is not usually deadly, it can significantly impair coffee plants by disrupting their growth and fruit production, leading to defoliation and negatively impacting their vegetative development (Figure 1). This can lead to polyetic epidemics that persist and recur over multiple growing seasons (Thalhinhas et al 2017, 5). The disease severity in one year can directly impact the cropping potential in the following year (Funlayo et al. 2017, 60).

In July 1986, Coffee Leaf Rust (CLR) was discovered in the Alston district in the parish of Clarendon Jamaica. Subsequently by 1987 CLR spread to all major coffee production areas but was redistricted to lower elevations and in 1989 it was identified as Race II of the pathogen (CIB, 2008). Due to the hardship of the 2007-2008 global financial crisis affecting the Jamaican coffee industry, most farmers left fields unmaintained and switched focus to cash crops to support their households. Four (4) years later the expected potential upswing in the coffee market prices, motivated JBM farmers to increase production in 2012, unfortunately they were faced with the early signs of CLR (Rhiney et al. 2020, 1). Jamaica suffered an egregious outbreak in 2012, fields at higher altitudes that were left untreated began to experience CLR, these elevations were previously believed to be too cold for disease proliferation (Guido et al. 2018, 258). Around June/July of 2013 approximately 25% to 30% of coffee plants throughout the JBM's were infected with CLR, which caused a substantial decline in the crop's quantity and quality (Rhiney et al 2020, 1). The most noted impact of CLR disease is the reduction of quality and quantity of coffee beans, however the economic impact is also experienced through the necessity of expensive control methods (Funlayo et al. 2017, 60). Drop in coffee prices coincided with a price increase of agricultural inputs and the devaluation of Jamaican dollar (JMD), this compounded the economic burden for coffee production. There was approximately a 65% drop in the value of the JMD to the USD from 2000 to the end of 2015, and from 2009 to 2015 local fertiliser and chemicals prices increased by 15% (Gudio et al. 2018, 258). Exported value of coffee dropped to $13.8 million USD in 2012 due a declining demand from Japan, the effects of coffee berry borer and turmoil of Hurricane Sandy which caused physical damage and the further spread of CLR spores (Birthwright and Barker 2015, 43-44). Further decline in 2014, exported coffee valued at $13.5 million USD due to the same reasons, coupled with effects of the spread of CLR (Birthwright and Barker 2015, 43). The Jamaica Information Service reported in 2014, that over the previous three (3) years Jamaica experienced annual losses in revenue valued at $10 million USD due to coffee leaf rust infestation (Birthwright and Barker 2015, 44). Though Jamaica exports only contributed 0.02% to the global supply in 2015, it was valued 30 million USD, due to the receiving the highest unit price for (JBM) *C. arabica* green coffee beans (Daly et al. 2018, 17). The unit price for green/unroasted coffee beans from Jamaica was $21.03 US per kg in 2015, which was approximately quintuple the average price for *Arabica* beans $4.42 US per kg (Daly et al 2018, 29). By 2016 coffee accounted for 83% of traditional agricultural exports earning 23 million USD. Over a ten-year period of 2012-2022 an average of 25 million USD per annum was earned from the coffee industry (BOJ 2015; Spence 2022). Nevertheless, since 2000 the Jamaican coffee industry have faced a 58% decline in export earnings (Birthwright and Mighty 2023, 2).

The main form of control used by developing countries' farmers are usually conventional broad-spectrum synthetic chemicals. Which have been evidently harmful to natural resources, flora and fauna and has hazardous implications on human health (Mc Donald, Emanuel and Robinson 2021, 51). Currently, Jamaican farmers still have difficulty managing the disease without synthetic chemicals. The environment is polluted with persistent synthetic agricultural chemical compounds, it has been reported, Jamaican farmers have habitually mixed endosulfan with Kocide (Cu-based fungicide and an OP either; diazinon, isazofos, dimethoate or profenofos) or a pyrethroid (permethrin or cypermethrin), primarily to combat the coffee leaf rust and leaf miner (Robinson and Mansingh 1999, 130). It was found that copper base fungicides are highly effective and commonly used which can cause a build-up of highly hazardous chemical residue in the environment (Funlayo et al. 2017, 60). The three JBM coffee production parishes, have different elevations and terroir which affect the lifecycle of coffee significantly, through its moderation of temperature, timing of crop, management practices and quality of coffee, vary between communities (Guido et al. 2020, 9-10). Since 2012 CLR has been an environmental challenge and one of the more persistent issues in Jamaican coffee production, which continuously affects the livelihood of tens of thousands of people who depend on the coffee value chain (Rhiney et al 2020,1).

The Jamaican coffee value chain is a significant contributor to the economy, as one of the main agricultural commodities for foreign exchange. The industry's value chain employs approximately 120,000 people locally (BOJ 2015; Guido et al. 2018, 255). The island is famous for the flavour profile of the Typica variety which is highly susceptible to CLR. *Coffea arabica* var. *typica* is the main variety grown in Jamaica, the quality of this species' variety combined with the terroir of the geographical location gives the JBM a distinct flavour. The coffee can be described as mild smooth with an earthy, deep aroma with hints of chocolate, walnut, banana, and cedar (Mighty and Granco 2021, 3). A Geographic Indication (GI) was registered to protect the JBM brand, specifying the unique geographical location and climatic factors required to contribute to the singularity of the coffee (Daly et al. 2018, 28). Therefore, due to this variety's reputation it is of utmost importance to determine possible environment friendly CLR control methods to improve yield, quality, consumer, and operator safety. Terra Vera Technology (TV) presents a safer substitute for highly hazardous pesticides (HHP), utilising a non-toxic, all-natural formulation that supports plant protection and helps mitigate pathogenic stress. (Goodridge et al. 2023, 139). TV was investigated as an alternative decontamination solution, which was determined to have a 77.8% and 66.7% effectiveness against 10 bacterial and 18 fungi targets respectively (Ozongwu et al. 2023). Also, TV was effective at the reduction of postharvest microbial activity on *Cannabis* plants (Cannabis and Tech Today 2023). This study was conducted in Blue Mountain region of Brandon Hill, St Andrew, Jamaica. The CLR disease severity at Brandon Hill, was assessed with the use of a standard area diagram severity chart from Belan et al. 2020, 4 (Figure 2). Two concentrations of TV were compared against controls to determine the efficacy of TV. This investigation aims to assess the potential usage of TV technology, in supressing and reducing the incidence of CLR (*Hemileia vastatrix*) on coffee production of Jamaica Blue Mountain (JBM) coffee located in Brandon Hill, St Andrew, Jamaica (Goodridge et al. 2023, 139).

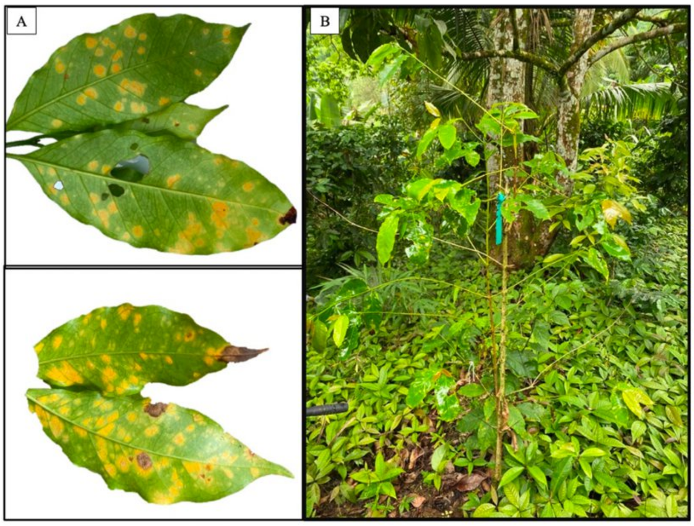

Figure 1. Symptoms of CLR disease presenting (A) spores and lesions on coffee leaves and (B) severe defoliation of coffee plant, in Brandon Hill, Jamaica. (Personal images).

MATERIALS AND METHODOLOGY

1. Study site

“The district of Brandon Hill is in the parish of West Rural St. Andrew, in the eastern part of the island Jamaica. The altitude and hilly terrain are exceptionally suitable for the cultivation of high-quality JBM coffee. This district is one of the main producers of coffee beans within the St. Andrew parish and when compared to other coffee producing districts, it has the largest number of registered active coffee farmers. The St. Andrew parish accommodates approximately 2,450 active farmers and there are an estimated 174 coffee farmers settled in the Brandon Hill district (Henry and Feola 2013, 60). Most of the parish’s coffee is produced by smallholder farmers, 44 % of farmers cultivate on land ranging from 1 to 4 acres and 34 % cultivate on less than 1 acre of land, for a total of 787 acres (Henry and Feola 2013, 60). Jamaican coffee farms are generally cultivated within an agroforestry system, which provides shade to coffee plants and diversifies the farmer’s income” (Goodridge et al. 2023, 140).

2. Establishment of research plot

“JACRA is a statutory body which falls under the Ministry of Agriculture and Fisheries. The regulatory authority is tasked with the mandate of providing the regulatory functions of the cocoa, coffee, and coconut industries in Jamaica. A preliminary survey was conducted with JACRA officials to determine a suitable study site with incidence of CLR and no recent usage of fungicides, for establishment of a research plot in the coffee production region of St Andrew, Jamaica. A coffee farm in the Brandon Hill, St Andrew coffee growing district was selected based on the confirmation of CLR disease and the ability to acquire confirmation of no recent application of fungicide, over the last three cropping cycles for the farm in question, and the neighbouring coffee farms bordering or adjacent to the farm selected. Consent was granted from JACRA and the owner of the smallholder coffee farm, permitting and facilitating the research investigation” (Goodridge et al. 2023, 141).

3. Experimental design

“The entire six-acre smallholder coffee farm located in Brandon Hill coffee growing district was scouted, to estimate the severity of CLR present for determination of incident levels using a standard area diagram (Figure 2). A total of sixty (60) coffee plants were selected based on established severity levels ranging from 1 (being lowest) to 6 (being highest). Four (4) experimental conditions were established with fifteen (15) coffee plants per experimental condition, for weekly assessment. The four (4) experimental conditions are as follows:

- 15 coffee plants with no treatment.
- 15 coffee plants treated with Reverse Osmosis water (RO water) only.
- 15 coffee plants treated with a concentration of 2:1 TV solution (two parts RO water to one part Terra Vera technology).
- 15 coffee plants treated with a concentration of 3:1 TV solution (three parts RO water to one part Terra Vera technology).

All 60 coffee plants selected as part of the experimental design, were monitored, and assessed weekly for a total period of nine (9) weeks between July and September 2022” (Goodridge et al. 2023, 141).

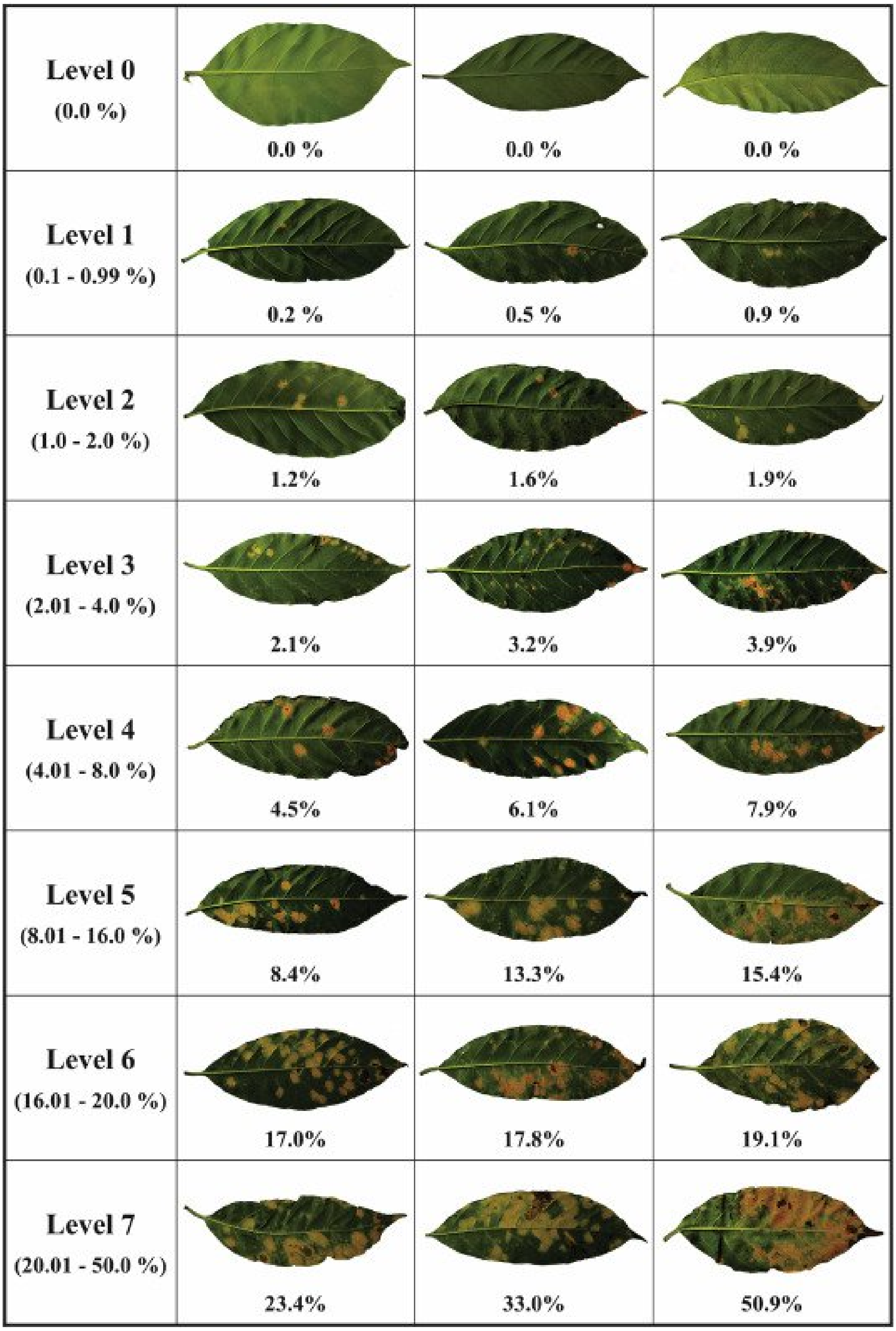

Figure 2. "Standard area diagram constructed with color photographs to aid in estimating the severity of coffee leaf rust (*Hemileia vastatrix)* in conilon coffee (Coffea canephora). The numbers represent the percentage of diseased leaf area containing uredospores/urediniospores of the pathogen, disregarding the light- yellow halo around the lesions (Belan et al. 2020, 4)" (Goodridge et al. 2023, 141).

4. Preparation of Terra Vera stock solution

"A full bag of the precursor powder was added to a 1-gallon bucket of RO water. The contents were mixed thoroughly to ensure the precursor powder was completely dissolved in accordance with manufacture protocol. Three (3) buckets were placed under the Terra Vera electrolysis unit located at the Life Science department at the University of the West Indies, Mona Campus Jamaica, with the respective hoses for the precursor concentrate, RO water and the collection of stock solution. The power switch was turned on and the Terra Vera electrolysis unit was allowed to calibrate to optimum conditions before the collection of the Terra Vera stock solution. Once the sufficient volume of stock solution was collected, the electrolysis unit was switched off and the Terra Vera stock solution was stored in a cool, dark area before being transported to the Brandon Hill coffee growing district to be utilised as per the experimental design" (Goodridge et al. 2023, 141).

5. Application of Terra Vera and RO water

"A concentrated stock solution of Terra Vera technology was prepared weekly to ensure the solution of Terra Vera chemistry was activated. The fifteen (15) coffee plants for each treatment were conducted in a randomized block design (each experimental condition having a range of severity levels from 1-6 (Figure 2) across the 6-acre coffee plot with the aim of creating clusters of plants with different microclimates for each experimental condition assessed in the study. Two separate hydraulic backpack sprayers were procured for the applications described above: one for the application of Terra Vera (2:1 and 3:1 concentrations) and one for the application of the RO water. The same backpack sprayer operator applied the Terra Vera technology and the RO water weekly. A total of eight applications were conducted on Tuesdays between the hours of 8 am and 11 am on a weekly basis. During the applications the backpack sprayer operators ensured the leaves of the plants of both the abaxial and adaxial surfaces, were sprayed with either the RO water or the appropriate Terra Vera concentration (2:1 or 3:1)" (Goodridge et al. 2023, 141).

6. Laboratory identification of *Hemileia vastatrix*

"CLR disease-presenting leaf samples were collected and transported in sterile specimen bags, to the Mycology Laboratory of the University of the West Indies Department of Microbiology, Mona Campus, Jamaica. Using the Sellotape mount technique, spores were prepared for direct microscopy by placing one drop of the commonly utilised fungal stain Lactophenol Cotton Blue (LCB), onto a glass slide for direct visualisation of fungal elements. A piece of tape was pressed down onto the spore mass on the leaf and transferred to the LCB by carefully pressing onto the surface of the glass slide. The sample preparation was placed directly onto a light microscope stage and read under x40 (4000) magnification for the visualisation of the spores. Processing of samples was conducted within a Class II Biological Safety Cabinet, to minimise potential environmental contamination and exposure risks associated with the sample" (Goodridge et al. 2023, 141).

7. Data collection

"Each week the prevalence and severity of CLR was assessed and estimated using a standard area diagram with colour photographs (Figure 2) to aid in estimating the severity of disease (Belan et al, 2020, 4). A marked region of each plant consisting of three (3) or more branches, was used to estimate and document disease severity within each experimental condition and the most appropriate/representative severity rating was applied to the plant. The severity of disease for each plant within each treatment condition was estimated and the average (mean, mode, median) and relative changes in severity levels were calculated. The efficacy of TV technology in reducing the severity of CLR was determined based on severity levels of CLR assessed throughout the nine-weeks of the observational period. Five (5) coffee plants per experimental treatment were selected for weekly photographs of the abaxial and adaxial surfaces of leaves, taken throughout the experimental protocol" (Goodridge et al. 2023, 142).

8. Statistical analysis

"A statistical analysis was conducted using the Kruskal Wallis and Mann-Whitney tests, where the treatments were used as fixed effects in the completely randomized plot layout. The software program used for the analysis was SPSS 28.0.0.0 (190). In all cases, significant differences were defined as those with $p < 0.05$" (Goodridge et al. 2023, 142).

RESULTS

A: Photographed Examples of CLR Disease Severity Levels Initial and After Applications from each Treatment.

Table 1: Displaying coffee leaves' abaxial surfaces showing CLR disease severity level initial and after TV applications from each treatment. (Personal images)

Initial	After
Level 4 ***Treatment: 2:1 TV***	***Level 2***
	
Level 4 ***Treatment: 3:1 TV***	***Level 4***
	
Level 5 ***Treatment: RO water***	***Level 6***
	
Level 3 ***Treatment: No treatment***	***Level 7***
	

B: Photographed Examples of CLR Greatest Reduction and Greatest Increase in Disease Severity Level of a Single Plant.

Table 2: Displaying coffee leaves' abaxial surfaces, showing CLR greatest reduction and greatest increase in disease severity level of a single plant after TV applications. (Personal images)

<table>
<tr><th colspan="2">Treatment: 3:1 TV</th></tr>
<tr><th>Initial</th><th>After</th></tr>
<tr><td colspan="2">Level 6 Greatest reduction in disease severity #47 Level 3</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Level 4 Highest increase in disease severity #60 Level 7</td></tr>
<tr><td></td><td></td></tr>
</table>

1. Disease Severity

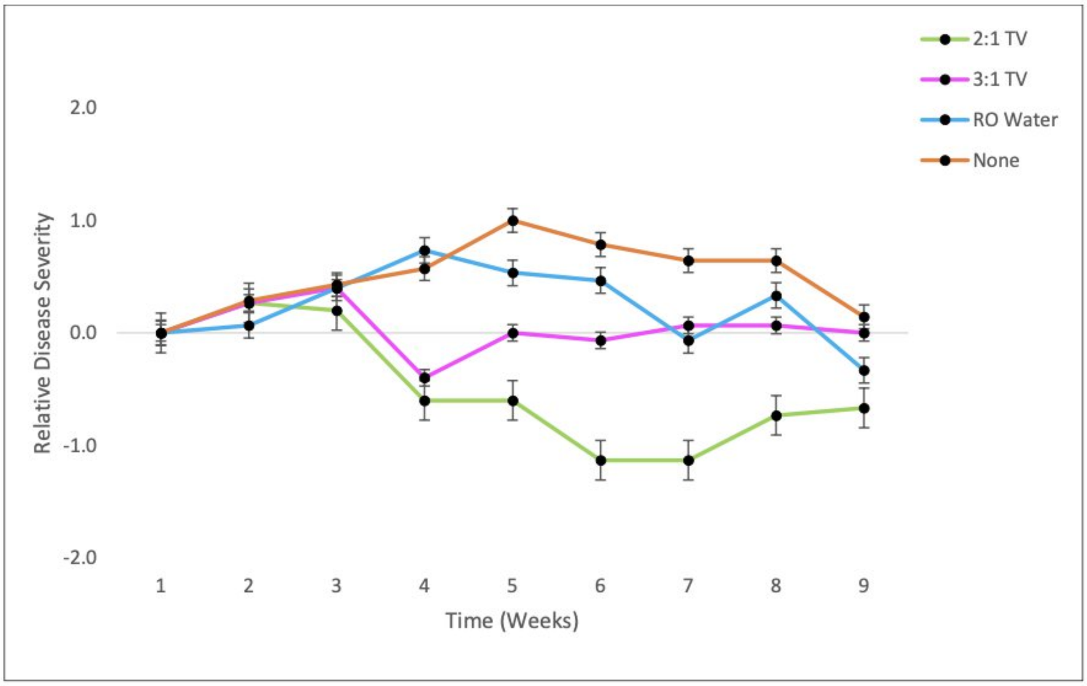

Figure 3. “Average relative change in CLR disease severity levels for all four experimental conditions, over time” (Goodridge et al. 2023, 142).

2. 2:1 TV treatment

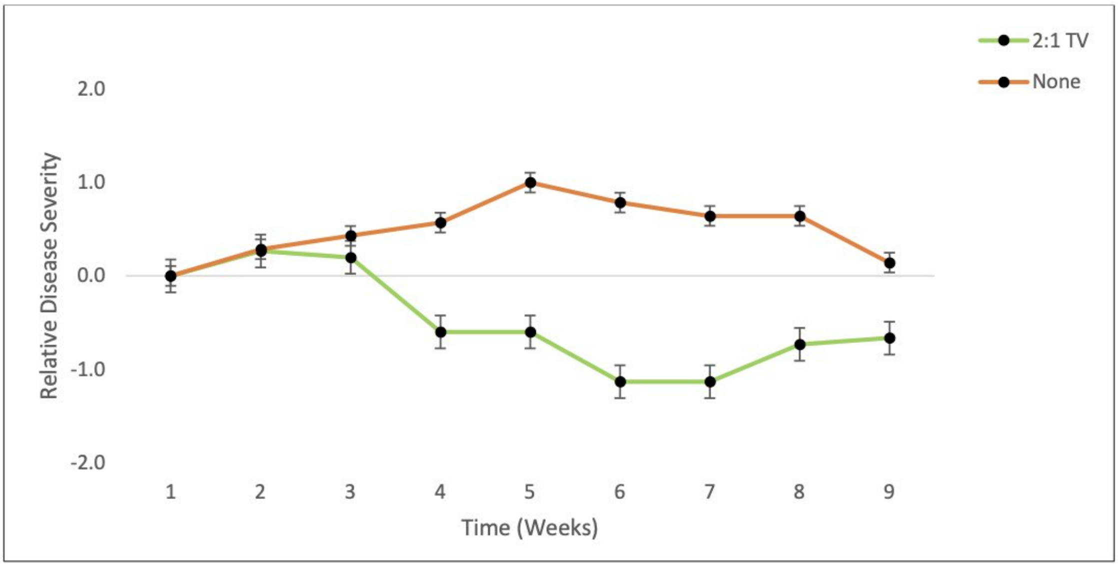

Figure 4. “Comparison of average relative change in CLR disease severity levels for 2:1 TV treatment and no-application study conditions” (Goodridge et al. 2023, 142).

3. Comparative Cost of Terra Vera with Traditional Treatment

Table 3. Comparative cost assessment of using Terra Vera verses traditional treatment for the suppression of coffee leaf rust in Jamaica.

TERRA VERA					TILT				
Inputs	**Unit**	**Number**	**Unit cost ($J)**	**Total ($J)**	**Inputs**	**Unit**	**Number**	**Unit cost ($J)**	**Total ($J)**
Percussor amino acid salt RMD	Kg	7	16607.14	116250.00	Concentrated bottle of Tilt	L	1	13656.27	13,656.27
RO H_2O for dissolving RMD	Gal	5	70.00	350.00	Tilt standard dilution	Gal	42	325.15	13,656.27
RO H_2O for electrolysis	Gal	5	70.00	350.00	*NA*	*NA*	*NA*	*NA*	*NA*
Concentrated TV chemisty	Gal	60	1949.17	116950.00	*NA*	*NA*	*NA*	*NA*	*NA*
RO H_2O for 2:1 dilution	Gal	5	70.00	350.00	*NA*	*NA*	*NA*	*NA*	*NA*
Option 1 STATEMENTS					**Option 2 STATEMENTS**				
Concentrated TV for application	Gal	14	1949.17	27288.38	Diluted Tilt for application	Gal	42	325.15	13,656.27
Labour to spray	Manday	1	5000.00	5000.00	Labour to spray	Manday	1	5000.00	5000.00
Cost of Terra Vera + labour	**Acre**	**1**	34248.38	**34248.38**	**Cost of Tilt + labour**	**Acre**	**1**	18656.27	**18,656.27**
Footnote:Std sprayer capcity	Gal	4	NA	NA	Footnote:Std sprayer capcity	Gal	4	NA	NA
Footnote: Sprayer filled of 2:1 TV solution		$140.00 + $1,949.17		2089.17	Footnote: Sprayer filled of Tilt solution		4 Gal x $325.15		1300.60
Footnote:Acre uses 28 Gal RO water for 2:1 TV			28 gal x $70	1960.00					
Footnote: Initial investment in the Terra Vera Brawndo TM system				5,425,000					

A comparative assessment of using Terra Vera technology verses Tilt in the suppression of CLR in Brandon Hill, Jamaica. It can cost a farmer an estimated $1,300.60 JMD to fill a four (4) gallon standard backpack sprayer of Tilt solution compared to $2,089.17 JMD to fill with a dilution of 2:1 Terra Vera (Table 3). Therefore, it can potentially cost an estimated $34,248.38 JMD to use Terra Vera verses $18,656.27 JMD to use Tilt for application to an acre of coffee plants (Table 3). This high cost and method of producing Terra Vera solution does not support a direct-to-consumer relationship with small holder famers.

DISCUSSION

The two controls displayed the highest average relative disease severity levels of all the coffee plants assessed (Figure 3). The 2:1 TV treated plants' relative change in CLR disease severity was significantly (< 0.05) different compared to the controls and 3:1 (Figure 3, Figure 4). The observations may suggest that the use of TV has some level of suppression of CLR (Table 1, Table 2) (Figure 3, Figure 4).

The island's reputation is associated with the Typica variety's flavour profile hence, this limits farmers ability to cultivate different varieties, without risking their primary export market (Guido et al. 2020,25). This dependence and lack of effective alternative disease management options, makes chemical control of CLR the necessary choice. Chemical control is a significant social concern, environmental hazard, and economic burden, particular for small holder famers. The copper-based fungicides which are commonly used as preventative treatments, whereas systemic fungicides (epoxiconazole, pyraclostrobin) are used as curative treatments (Talhinhas et al. 2017, 6-7). Coffee farmers have been advised to use products such as Tilt (1L = $13,656.72 JMD) (more accessible) and Opera against CLR (Myers 2022). Tilt's active ingredient is propiconazole, which is very toxic to aquatic life (prolong effects), and has a significant effect on development of abnormalities and embryonic death in a planktonic crustacean (*Daphina magna*) (Kast-Hutcheson, Rider and LeBlanc 2001). It also has the potential to affect fertility or unborn children and is harmful if ingested. Opera's two active ingredients are epoxiconazole, which is moderately toxic to: earthworms, most aquatic organisms, birds, and honeybees. In combination with pyraclostrobin, which can decrease nutrient metabolism, immune competence and significantly affect the development of honeybees (Xiong et al. 2023, 7). In humans, it can cause eye injury and skin irritation. CLR management has demonstrated to be toilsome with limited/lack of financing or investment, regardless of climate change impact (Guido et al. 2020, 26). For a small holder farmer to use any of these traditional products the requirements are very simple; an investment in a mixing drum, a backpack sprayer for application (or hired labour), Personal Protective Equipment (PPE) and have accessibility to clean water for dilution.

Whereas, the Terra Vera formulation requires a costly initial investment of the amino acid activator system, available in three sizes and output capacities to suit various operations. Brawndo TL (2.5 gal/hour, $55,000 USD), BrawndoTM (1.5 gal/hour, $35,000) (Table 3) and Brawndo TS (0.2 gal/hour, $1,000 USD). These systems activate a range of precursor amino acid salts, each designed for specific plant growth stages and benefits, including: RMD ($750 USD): Boots plant immune system and optimises root, stalk, and flower growth. THRV ($5-$50 USD): Enhances plant growth and development during vegetative and flowering stages. GRDN ($1,150 USD): Prevents and controls pest, diseases, and viruses, suitable for indoor and outdoor use. IV ($25 - $1,200 USD): Improves plant growth during various stages of vegetative and flower development (Terra Vera 2023). These activator systems and amino acid salts work together to provide a comprehensive solution for plant growth and development. The amino acid activator system uses electrolysis to produce an amino acid concentrate with an unstable chemistry, that can be diluted as needed and naturally degrades in the environment (Robinson, Emanuel and Robinson 2023). The comparative cost assessment estimated cost of applying Terra Vera to one acre of coffee plants is approximately $34,248.38 JMD, nearly double the $18,656.27 JMD required for Tilt (Table 3).

Farmer Myers was asked if he would recommend TV technology to his colleagues in Brandon Hill, his response was, “Yes” as he had “observed it to be environmentally friendly, safe for him use” and he “could see it working”. He also stated that he believed that “even better results would have been seen, had the experiment not been conducted in the rainy season where the results may not have been so promising” (Myers 2022; Goodridge et al. 2023, 144). Other concerns of his was the affordability, accessibility, and the shelf life of the TV because these elements are what would determine farmers use of TV. As cost of production is a major concern and deterrent for producing coffee. Farmers/Sprayers will also be free of the cost of purchasing PPE due to the operator safety of TV technology. Farmer Myers highlighted the fact that he was able to use TV without PPE, as compared to traditional treatment (Myers 2022; Goodridge et al. 2023, 144). Farmer Myers also expressed that when he uses traditional fungicides he feels unwell after use, compared to his experience with TV this didn’t occur (Goodridge et al. 2023, 144).

From the comparative cost assessment, the short-term cost of TV will be more expensive than traditional treatment (Table 3). However, the long-term overall value and potential benefits with the use of Terra Vera to consumers, operators, and environment, compared to the traditional synthetic chemicals, can possibly outweigh its economic cost. Jamaica coffee farmers do not have the financial capacity and technical knowledge to purchase, maintain or manage such a system (Table 3). However, a more effective recommendation is to develop a Public-Private Partnership (PPP) among all the parties involved in the Jamaican coffee value chain, where the economic burden of the initial TV technology investments, maintenance and future benefits are shared. The responsibility, management, distribution and resale of TV systems and products should be a coordinated effort by the PPP, which should include the Ministry of Agriculture's JACRA and RADA, pesticide control authority, private sector, and Coffee Growers association representatives. Though Terra Verra has a higher monetary cost (Table 3), Jamaica's government with the support of the PPP can potentially implement subsidies on environment friendly non-hazardous agriculture products. To make the cost more attractive to agricultural distributors/retailers and farmers. Therefore, alternative products such as TV ($2,089.17 JMD) can be more accessible to the farmer at a cost similar to filling a 4-gallon sprayer with Tilt ($1300.60 JMD) (Table 3) or other hazardous chemicals. Additionally, the PPP can offer a higher monetary value to producers of organic coffee beans, similar to the fairtrade organic coffee farmers incentive. Thereby, improving economic gains and the consistence of a higher quality and quantity of coffee produced, that is free of hazardous chemicals and diseases.

To further assist in the successful application of alternative products such as TV, a PPP can strengthen the access to knowledge, information and technology via extension services or workshops. Lastly, increasing farmer resilience to social and environmental hazards through improved weather observations, price forecasts and early warning of drought or CLR outbreaks (Guido et al. 2020, 27-29). Thus, improving the effectiveness and reduction of the amount of chemicals used for disease management (Rhiney et al. 2020, 2). Specifically, farmers equipped with alternative control strategies can refrain from culling and replacing Typica, thereby, protecting the JBM brand. The Brandon Hill coffee farmer expressed, "it would be preferred to save the coffee plants" and they are "willing to do anything to avoid culling and replacing the variety", however, "this method has been more financially feasible, due to high inputs and labour costs" (Myers 2022). Protection of the JBM brand can give Jamaica a competitive advantage to market and build the JBM brand, to enter new export markets. This can address three major challenges faced by the Jamaican coffee industry: reliance on a single export market, low productivity and JBM brand building (Daly et al 2018, 30). Which may give Jamaica a potential increase in foreign exchange and economic gains for all parties involved in the coffee value chain. It can especially benefit the livelihood and reduce food insecurity of smallholder JBM farmers. Further investigation of TV is warranted to determine the most adequate application practices in accordance with the local agroecological factors and epidemiology. On the other types of cultivars and including sanitation with TV may aid in the TV technology having a greater efficacy than what was observed during this investigation.

CONCLUSION

The farmer indicated that the following year (2023), the TV treated plants health improved and they bloomed producing a lot of quality coffee beans (Devon Myers, direct phone call with author, October 11, 2023). Utilising TV technology as an antifungal treatment shows potential as an alternative strategy for managing CLR in coffee cultivation. However, the high cost and production method of the Terra Vera solution limits its accessibility and practicality for direct sale and distribution to smallholder farmers. The smallholder farmers would require further assistance inclusive of but not limited to, financial assistance, improved extension services and forecasting systems (CLR and climate) to ensure correct timing of application and concentration of TV.

REFERENCES

Bank of Jamaica (BOJ). 2015. Jamaica in figures 2013. Bank of Jamaica, Kingston. http://www.boj.org.jm/uploads/pdf/jam_figures/jam_figures_2013.pdf

Belan, Leônidas L., Leonardo Leoni Belan, Anatan da Matta Rafael, et al. 2020. "Standard Area Diagram with Colour Photographs to Estimate the Severity of Coffee Leaf Rust in Coffea Canephora." *Crop Protection* 130 (2020): 105077.

Birthwright, Anne-Teresa and David Barker. 2015. "Double Exposure and Coffee Farming: A Case Study of the Vulnerability and Livelihood Experiences among Small Farmers in Frankfield, Jamaica." *Caribbean Geography* 20: 41.

Birthwright, Anne-Teresa and Mario Mighty. 2023 "Risky Business: Modeling the Future of Jamaica's Coffee Production in a Changing Climate." *Climate* 11, no. 6 (2023): 122.

Cannabis and Tech Today. 2023. "The Lab Investigates: Root Propagation and Powdery Mildew Treatment" Technology. July 11th 2023. https://cannatechtoday.com/the-lab-investigates-root-propagation-and-powdery-mildew-treatment/

Coffee Industry Board (CIB). 2008. "Status of Coffee Leaf Rust (*Hemileia vastatrix*) in Jamaica" Coffee Leaf Rust Workshop CICafe Costa Rica March 13-14th . PowerPoint presentation.

Daly, Jack, Danny Hamrick, Karina Fernandez-Stark and Penny Bamber. 2018. "Jamaica in the Arabica Coffee Global Value Chain". 1-40. *researchgate.net* DOI: http://dx.doi.org/10.13140/RG.2.2.35977.95849

Funlayo, A., Adepoju, Omotayo O. Adenuga, E. F. Mapayi, Olayinka O. Olaniyi. 2017. "Coffee: Botany, Distribution, Diversity, Chemical Composition and its Management." *Journal Agriculture and Veterinary Science* 10, no. 7: 57-62. DOI: 10.9790/2380-1007035762

Goodridge, Jed J., Chika J. Ozongwu, Machel A. Emanuel, Dwight Robinson and John Lindo. 2023. "Terra vera technology usage for suppression of coffee leaf rust Hemileia vastatrix in Brandon Hill, Jamaica."*Horticult Int J* 7, no. 4 (2023): 139-144. DOI: 10.15406/hij.2023.07.00287

Guido, Zack, Tim Finan, Kevon Rhiney, Malgosia Madajewicz, Valerie Rountree, Elizabeth Johnson, and Gusland McCook. 2018. "The Stresses and Dynamics of Smallholder Coffee Systems in Jamaica's Blue Mountains: A Case for the Potential Role of Climate Services." *Climatic Change* 147: 253-266. DOI: https://doi.org/10.1007/s10584-017-2125-7

Guido, Zack, Chris Knudson, Tim Finan, Malgosia Madajewicz, and Kevon Rhiney. 2020. "Shocks and Cherries: The Production of Vulnerability Among Smallholder Coffee Farmers in Jamaica." *World Development* 132 (2020): 104979. DOI: https://doi.org/10.1016/j.worlddev.2020.104979

Henry, Dwayne, and Giuseppe Feola. 2013. "Pesticide-handling Practices of Smallholder Coffee Farmers in Eastern Jamaica." *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 114, no. 1: 59-67. http://www.jarts.info/index.php/jarts/article/view/2013030542613

Keith, Lisa M., Tracie K. Matsumoto, Lionel S. Sugiyama, et al. 2023. "First Report of the Physiological Race XXIV of Hemileia Vastatrix (Coffee Leaf Rust) in Hawai'i.". *Plant Disease*: Vol. 107 No. 8. 2528. DOI: https://doi.org/10.1094/PDIS-03-23-0460-PDN

Koutouleas, Athina, Hans Jørgen Lyngs Jørgensen, Birgit Jensen, Jens-PeterBarnekow Lillesø, Alexander Junge, and Anders Ræbild. 2019. "On the Hunt for the Alternate Host of Hemileia Vastatrix." *Ecology and evolution* 9, no. 23: 13619-13631. DOI: https://doi.org/10.1002/ece3.5755

Kast-Hutcheson, Karen, Cynthia V. Rider, and Gerald A. LeBlanc. 2001. "The fungicide propiconazole interferes with embryonic development of the crustacean Daphnia magna." *Environmental Toxicology and Chemistry: An International Journal* 20, no. 3: 502-509. DOI: https://doi.org/10.1002/etc.5620200308

Mc Donald, N. Nadia, Machel Emanuel, and Dwight, Robinson. 2021. "The Efficacy of Alternative (Biorational) Insecticides in Suppressing Damage Caused by Insect Pests Affecting Callaloo, Amaranth Xanthosoma and Pak Choy, Brassica Rapa, Production in Jamaica." *Horticult Int J* 5, no. 2 : 51-59. DOI: 10.15406/hij.2021.05.00203

Mighty, Mario and Gabriel Granco. 2021. "Modeling Profitability in the Jamaican Coffee Industry." *Agriculture* 11, no. 2:121. DOI: https://doi.org/10.3390/agriculture11020121

Myers, Devon R. 2022. "Suppression of Coffee Leaf Rust (Hemileia vasatatrix) with the use of Terra Vera Technology on Blue Mountain Coffee in Brandon Hill, Jamaica" *Farmer interview*, Farmer's point of view. Interview by Jed Goodridge (Author) September 6th 2022.

Ozongwu, Chika, A. Kaplan, M. McGowan, et al. 2023. "Assessing the Use of an Alternative Solution for the Microbial Decontamination of Cannabis Production Facilities". *International Society for Horticultural Science (ISHS)*, VII *International Conference Postharvest Unlimited* & XII *International Symposium on Postharvest Quality of Ornamental Plants. Poster Session 1: Pathogens and Pests.* Wageningen University & Research, The Netherlands. 14-17 May. (Not yet published)

Robinson, Dwight E., and Ajai Mansingh 1999. "Insecticide Contamination of Jamaican Environment. IV. Transport of the Residues Coffee Plantations in the Blue Mountains to Coastal Waters in Eastern Jamaica." *Environmental Monitoring and Assessment* 54: 125-142. DOI: https://doi.org/10.1023/A:1005806815959

Robinson, Roy, Machel Emanuel and Dwight Robinson. 2023. "The use of Terra Vera Technology in Supressing Pest Pressure for Cabbage *Brassica olercea* var. *capitata* Production in Jamaica", (Poster, Society for Ethnobotany & Society for Economic Botany (SEB/SoE) joint conference, Atlanta USA, June 4-9 2023. https://drive.google.com/open?id=1oCqXEhfOoLoBkwWzTd8DThY7ui6mjdhR

Rhiney, Kevon, Chris Knudson, and Zack Guido. 2020. "Cultivating Crisis: Coffee, Smallholder Vulnerability, and the Uneven Sociomaterial consequences of the leaf rust epidemic in Jamaica." *Annals of the American Association of Geographers* 111, no. 2: 440-458. DOI: https://doi.org/10.1080/24694452.2020.1775543

Sera, Gustavo Hiroshi, Carlos Henrique Siqueira de Carvalho, Juliana Costa de Rezende Abrahão, Edson Ampélio Pozza, José Braz Matiello, Saulo Roque de Almeida, Lucas Bartelega, and Deila Magna dos Santos Botelho. 2022. "Coffee Leaf Rust in Brazil: Historical Events, Current Situation, and Control Measures." *Agronomy* 12, no. 2: 496. 1-19. DOI: https://doi.org/10.3390/agronomy12020496

Spence, Chanel, 2022. "JCEA on the Drive to Increase Coffee Exports". Jamaica Information Services January 28, 2022. https://jis.gov.jm/jcea-on-drive-to-increase-export-of-coffee/.

Talhinhas, Pedro, Dora Batista, Inês Diniz, Ana Vieira, Diogo N. Silva, Andreia Loureiro, et al. 2017. "The coffee leaf rust pathogen *Hemileia vastatrix*: one and a half centuries around the tropics." *Molecular plant pathology* 18, no. 8: 1039. DOI: https://doi.org/10.1111%2Fmpp.12512

Terra Vera. 2023. Accessed August 8, 2023. https://terravera.com

Xiong, Manqiong, Gan Qin, Lizhu Wang, et al. 2023. "Field Recommended Concentrations of Pyraclostrobin Exposure Disturb the Development and Immune Response of Worker Bees (Apis mellifera L.) Larvae and Pupae." *Frontiers in Physiology* 14: 158. DOI: https://doi.org/10.3389/fphys.2023.1137264

Acknowledgments

The authors would like to thank Jamaica Agricultural Commodities Regulatory Authority JACRA for their assistance and approval in carrying out this investigation.

The authors would also like to thank Terra Vera Technology for supporting this investigation.

Conflicts of interest

Authors declare no conflict of interest exist.