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Panamá disease tropical race 4 in banana plantations in Mozambique: Disease intensity, spatial distribution and negative socio-economic impact

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***Fusarium oxysporum f. sp. cubense* Tropical Race 4 (Foc TR4) devastated the second-largest banana plantation farm in Northern Mozambique, resulting in an 86% loss of the Cavendish Williams banana area and the layoff of 88% of the workers. This study conducted a field survey with 119 soil and 26 crop samples and administered a questionnaire in a quasi-experimental design with two samples, randomly selected, of unemployed (n1=272) and employed at the banana company (n2=79), to assess disease intensity, spatial distribution, and its socioeconomic impact on ex-employees. The results indicated the presence of *F. oxysporum* in the soil within the plantation farm and in its surrounding areas, and *Foc* in plants outside the farm. Since other studies using PCR molecular tests have confirmed the presence of TR4 in surrounding areas, it is highly likely that *Foc* TR4 is present in plants outside the farm, confirming its spread. Unemployment had a negative socioeconomic impact, and families experienced restrictions on economic access to nutritious foods and food preferences. An adapting and integrated disease management approach combining resistant varieties, exclusion, biosecurity, and soil management for increasing banana production and stimulating labor demand through re-hiring the ex-employees could be considered to improve disease management and ex-employees' incomes.**

Key words: *Musa spp*, Panamá disease, *Fusarium oxysporum f. sp. cubense*, socio-economic impact.

INTRODUCTION

Banana (*Musa species*) is a crop of high socio-economic importance for Mozambique. Banana large-scale plantations are responsible for approximately 60% of banana production and constitute an important source of foreign exchange for the country's economy, generating an average of USD 40,000,000 per year (MASA, 2019). However, banana plantations are being confronted with the dissemination of Panama disease caused by the soil-borne fungus *Fusarium oxysporum f. sp. cubense* Tropical Race 4 (*Foc* TR4) (van Westerhoven et al., 2023; Viljoen et al., 2020). Systematic knowledge of disease intensity, spatial distribution, and its negative socio-economic impact in the affected areas is scarce and limits the design of effective sustainable disease management strategies that take into account income-generating opportunities for workers laid off due to the

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disease. TR4 is the most virulent race of *Foc* that attacks resistant Cavendish cultivars to *Foc* race 1, and a diverse range of local varieties not susceptible to *Foc* races 1 and 2 (Van Westerhoven et al., 2023; (Pérez-Vicente et al., 2014), and it can lead to a 100% loss of production if containment measures are not taken (FAO, 2019). Nonetheless, there are no effective methods to control Panama disease caused by *Foc* TR4 (Zhu et al., 2023; Pegg et al., 2019). Sources of resistance to TR4 are still unknown (Kumari et al., 2023), smallholder farmers are not aware of *Foc* TR4 (FAO, 2019), and knowledge of *Foc* TR4 epidemiology and soil management approaches are still limited (Dita et al., 2018). In Mozambique, *Foc* TR4 devastated the second-largest banana export plantation company, located in the district of Monapo, community of Metocheria in the province of Nampula (Viljoen et al., 2020). The plantation lost 86% (1250 ha) of the Cavendish Williams banana area. Banana exports to countries in Europe and the Middle East, and to South Africa, were dramatically reduced from approximately USD 9,410,000 in 2014 to USD 22,000 in 2018 (ITC Trade Map, 2019), and the company laid off about 88% (2,200) of its workers with serious socioeconomic consequences.

Disease intensity, spatial distribution and disease management

Disease intensity is determined by biotic factors (Dita et al., 2018), such as nematodes (*Radopholus similis*) and weevils (*C. sordidus and M. hemipterus*), and the Soil and Plant Microbiome (*Chthonomonas spp., Pseudomonas spp., and Tumebacillus genera*), as well as abiotic factors such as physical and chemical soil characteristics that make the soil suppressive (Pérez-Vicente et al., 2014; Pegg et al., 2019). Recent research indicated that the banana corm can play an important role in reducing the harm of Panama disease by slowing down TR4 infestation (Zhou et al., 2023), and the application of Streptomyces morookaensis strain improves soil properties and increases rhizosphere-associated microbes that are beneficial to banana growth, significantly reducing disease incidence of Panama disease (Zhu et al., 2023).

Spatial distribution of *Foc* is associated with pathogen dispersal (Pérez-Vicente et al., 2014), and anthropogenic factors are among the most determining factors of pathogen dispersal since they are driven by the basic needs of local communities. Men and women farmers living in the surroundings of infested areas may enter these areas to collect firewood and construction materials which host the pathogens and increase the risk of dispersal of *Foc*. They may also exchange asymptomatic but infected suckers as planting materials, contributing to the spreading of *Foc*. Therefore, producers should possess knowledge and capacity to prevent the disease.

Panama disease management is complex and requires the adoption of integrated and long-term disease management approaches that combine resistant varieties, exclusion, biosecurity, soil management, as well as innovative alternative options (Dita et al., 2018). Positive economic impacts have been reported with the adoption of any of the following disease management options (Staver et al., 2020): (i) improved exclusion, surveillance, eradication, and containment (ESEC) measures to reduce Foc TR4 spread, (ii) integrated crop and disease management (ICDM) to facilitate the production of partially *Fusarium* wilt of banana (FWB)-resistant cultivars on *Foc*-infested soils, (iii) conventional breeding of FWB-resistant cultivars (CBRC), and (iv) genetically modified (GM) FWB-resistant cultivars (GMRC).

Negative socio-economic impact of panamá disease tropical race 4

People laid off due to Panama disease became unemployed and experienced a reduction in income (Pérez-Vicente et al., 2014). Unemployment reduces an individual's levels of satisfaction with his/her vocational activity and financial situation, while the level of satisfaction with the financial situation is positively associated with income-yielding assets, savings, and unemployment benefits (Ahn et al., 2004). Unemployment duration can be short (less than 6 months) or long term (6 months or more) (Lindsay et al., 2003). von Scheve et al. (2017) found that individuals suffered significantly within the first year of unemployment and were more dissatisfied with life when they remained unemployed for a longer period. Other studies (Clark and Georgellis, 2013) found only little evidence of adaptation to unemployment within a time span of 5 years, and life events such as income changes affected people who experienced job loss (Georgellis et al., 2008).

Concerning leisure activities, the unemployed reported high levels of satisfaction (Esche, 2020), as they spend more time than the employed on non-work-related activities (Hoang and Knabe, 2021). Job expectations and the economic situation of the place where the unemployed person is located also affect individual satisfaction, with individuals located in areas with relatively high economic activities manifesting less dissatisfaction compared to individuals located in areas with little economic activity (Ahn et al., 2004).

Based on previous research on the impact of unemployment on well-being, the following four hypotheses were formulated: H1. Agricultural activity decreases satisfaction levels, particularly financial satisfaction, as it provides low monthly income. H2. Income increases from current activities increase satisfaction levels with well-being. H3. Unemployment benefit increases the satisfaction level, particularly

financial satisfaction, as it fills a temporary income drop from job loss. H4. The length of unemployment affects satisfaction levels negatively as it aggravates financial and emotional deprivations.

A major consequence of unemployment is the decrease in the quality of food consumed by families (US Department of Health and Human Services, 2023). Depending on the duration of the unemployment period, substantial changes in diet composition may have health implications (Smed et al., 2018). Families of the unemployed may be required to decrease the quantity of food intake, reduce food diversification, and eat what is locally available, not necessarily their food preferences.

The majority of rural households in Sub-Saharan Africa rely on small-scale agriculture, with an average farmland size of 2 ha, as their main source of livelihood. However, this does not guarantee food security, defined as "physical and economic access, at all times, to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Bank, 2023; Adeyanju et al., 2023). Agriculture contributes to food availability, as families can consume their own produced food. Still, other livelihood strategies, such as off-farm income, have been revealed to have the strongest significant influence on household food security compared to farm income (Tesfaye and Nayak, 2022; Mutea et al., 2019). Income provides families with physical access to food through purchasing the food needed to satisfy their dietary needs (Chakona, 2023) (FAO, IFAD, UNICEF, WFP, and WHO, 2022), and families with higher income are more likely to be food secure than families with lower income. Ex-employees of the banana plantation are likely to resume agricultural activities with low and unstable monthly income, decreasing economic access to nutritious foods and healthy diets (Chakona, 2023; Lee and Allen, 2022).

Objectives of the study

This study assessed the intensity and spatial distribution of Panamá disease caused by *Foc* TR4 in the surrounding areas of the affected banana plantation farm in the district of Monapo, Nampula province, from February to November 2019. The objectives of the study were twofold: firstly, to determine the occurrence of Panamá disease in banana production areas considered at risk of infestation and the level of smallholder farmers' awareness of Panamá disease.

Secondly, to ascertain the perceptions of ex-employees of the banana production farm on the magnitude of the negative socioeconomic impact of Panamá disease.

MATERIALS AND METHODS

Study area

The study was carried out in the district of Monapo, province of Nampula (Figure 1). The district has a population of 393,813 \ inhabitants and a public extension network with 13 extension workers to assist small farmers. The affected banana plantation farm is located in the Metocheria community, employs 572 workers, and explores 280 ha, out of the planned 1000 ha for the establishment of banana plantations by 2021. In the district of Monapo, there is a great expectation among ex-employees to be rehired to establish new banana plantations. The study was conducted from February to November 2019 in 5 communities: Monapo-Sede, Metocheria, Muchaleque, Nacololo, and Netia (Table 1), located in the surrounding areas of the affected banana plantation farm.

Table 1 lists the district, communities visited, the number of samples collected for studying disease intensity and its spatial distribution, and the number of unemployed, employed and small-producers interviewed.

Research design and sampling

Intensity of panamá disease in the fields of producers in the surrounding regions of banana plantation

A two phase field survey was conducted to evaluate the Incidence of Panamá Disease in affected areas.

Phase I

The sampling procedure consisted of, firstly, dividing the occupation map of the plantation farm into 12 squares of approximately 2145m2 each (Figure 2), according to the level of incidence of Panamá disease. Secondly, soil samples were taken in 7 (58%) of the 12 squares, which represented the actual area established for re-planting bananas.

Soil samples were collected within and outside the farm. Within the farm, 79 samples were collected, and squares of 200 x 200 m were used for sample collection, either in cultivated or abandoned areas. In the surrounding areas of the farm, 14 samples were collected, every 400 m, along the paths used by farm workers and the surrounding population.

Soil samples were collected 15-20 cm deep, weighing around 500 g. The samples were placed in paper envelopes, taken to the laboratory at the plantation farm, and left to dry for 48 h under natural conditions (Pérez-Vicente et al., 2014).

Phase II

Sampling of soil and plants was performed outside the farm, in the surrounding smallholders' banana plots, within a radius of no more than 500m from the protective fence. A total of 26 plant samples and the same number of soil samples were collected. Soils were collected around each sampled plant. One sample was collected per plant selected based on the symptoms of Panamá disease, such as yellowing from older to younger leaves, wilting of the plant, and splitting of the *pseudostem*. Using previously disinfected cutting instruments, a longitudinal cut was made in the center of the *pseudostem* of symptomatic banana plants to observe internal symptoms of reddish-brown discoloration of vascular tissue. A segment of plant tissue measuring approximately 5cm x 5cm was collected, from which a vascular thread was removed and wrapped in paper filter and placed inside a paper envelope. The segment of plant tissue was returned to the plant to cover the injury made, and finally reinforced with adhesive tape (Pérez-Vicente et al., 2014; Viljoen et al, 2020; Garcia-Bastidas, 2022). Individual semi-structured interviews were conducted with a non-probabilistic sample (n=124) of small banana producers in high-risk areas of infestation to evaluate smallholders farmers' awareness of Foc TR4.

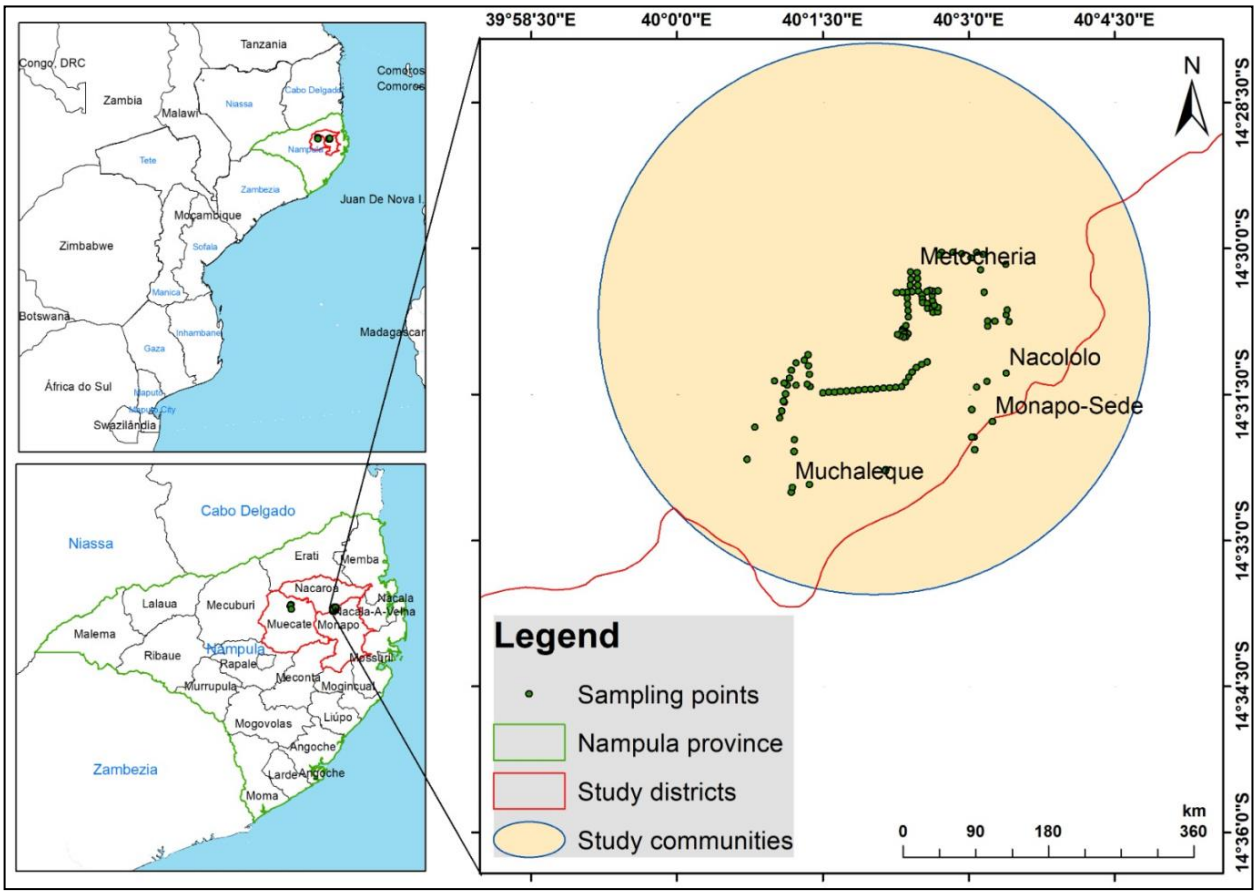

Figure 1. Nampula province and study communities.

Table 1. Research locations, soil and plant samples, number of unemployed, employed and small-producers interviewed.

District	Community	Soil samples		Plant samples	Unemployed	Employed	Small-producers
		Inside farm	Outside farm	Outside farm			
	Monapo-Sede	-	5	5	100	37	-
	Metocheria	79	19	5	52	14	71
Monapo	Muchaleque	-	12	12	37	-	-
	Nacololo	-	4	4	10	-	-
	Netia	-	-	-	73	28	53
Total	5	79	40	26	272	79	124

Laboratory analysis

The laboratory analysis of the samples was performed at the Culture Tissue Laboratory at the plantation farm. The fungus *F. oxysporum* was isolated in a Selective Fusarium Agar culture medium, where the dilution technique was used for soil samples and the incorporation method for plant tissue samples (Figure 3).

The soil serial dilution plate technique consisted of uniformly dispersing 1 ml of soil suspension on media. Briefly, 10 g of soil was suspended in 90 ml of distilled sterilized water, and then mixed thoroughly for 20 min. This suspension was used to prepare serial dilutions of 10^-2, 10^-3, 10^-4, and 10^-5. Each dilution was prepared by adding 1 ml of the soil suspension to 9 ml of sterilized distilled water. 1 ml of dilutions 2, 3, 4, and 5 was pipetted and transferred to the petri dishes in triplicate. By gently shaking the petri dishes, the inoculum was evenly spread over the surface of the Selective Fusarium Agar media, and incubated for 7 days at 27°C (Singleton et al., 1992; Leslie and Summerell, 2006; Pérez-Vicente et al., 2014).

The incorporation method consisted of planting small pieces of tissue on media. Vascular strands of pseudostem samples, collected from suspected infected banana plants were disinfected in 5% sodium hypochlorite for 1 min and subsequently washed three times in sterile distilled water, and dissected on sterile filter paper in

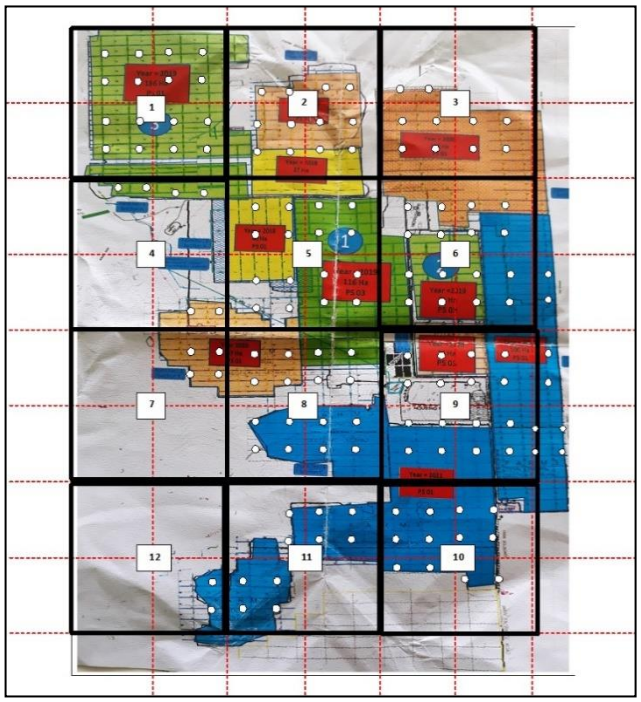

Figure 2. Sampling sites within the plantation farm.

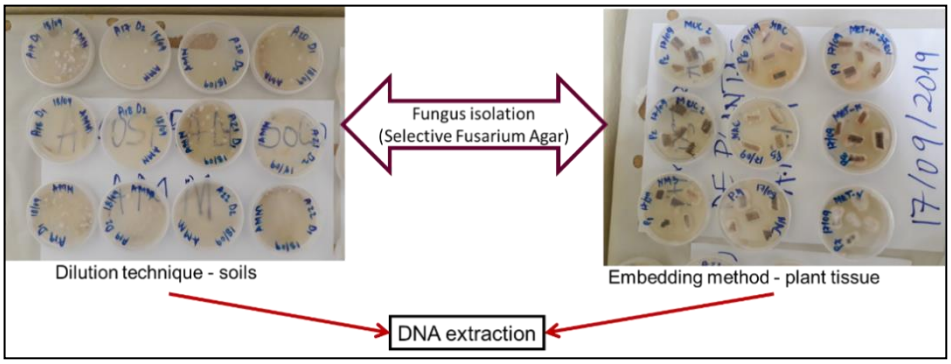

Figure 3. Laboratory analysis of samples - Culture tissue laboratory at plantation farm.

a paper envelope for 24h under natural conditions. Small pieces of vascular strands were cut into approximately 0.5 cm long and placed in petri plates with Selective Fusarium Agar media, and incubated for 5 days at 27°C. After 5 days, the fungal colonies were subcultured to obtain a pure culture (Leslie and Summerell, 2006; Pérez-Vicente et al., 2014). The subculture was preceded by a microscopic observation of the morphological characteristics of the mycelium and spores of the fungal colonies (Figure 4).

Morphologically, *F. oxysporum* is characterized by aerial mycelial growth, which can appear white, creamy, orange, pink, or violet depending on the media used for isolation. This fungus has two types of spores: conidia, which can be microconidia and macroconidia, and chlamydospores, which are resistance structures. Microconidia, in terms of shape, can be oval, elliptical, and reniform, generally without septa and unicellular. The macroconidia, in terms of shape, are fusiform, generally with 3 septa and 4 to 6 cells. The apical cell tends to be curved, sometimes ending hooked, and the basal cell has the shape of a foot (Ploetz, 2006; Leslie and Summerell, 2006; Viljoen et al., 2020; Garcia-Bastidas, 2022).

Mapping the current distribution of Panamá Disease in the plantation farm surrounding regions

The study utilized GPS to acquire geographic coordinate data, including latitude and longitude. Subsequently, the researchers employed Google Earth Pro software to analyze the geographic coordinate data and generate a distribution map of *F. oxysporum* (*Foc*) in the surrounding regions of the plantation farm.

Measurement of perceptions of banana plantation' workers on socio-economic impact of Panamá disease

A cross-sectional survey was implemented in a quasi-experimental design (Alreck and Settle, 2004; Kerlinger and Lee, 2000; Babbie,

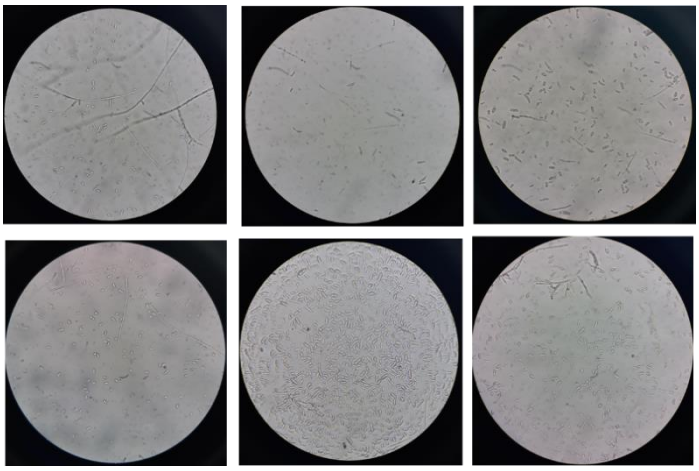

Figure 4. Microscopic observation of microconideos of *Fo/Foc.*

2007). A sample of former workers (n_1=272) and a sample of the current workers of the impacted banana plantation (n_2= 79), were randomly selected.

Data collection and analysis

A questionnaire was designed to assess the perceptions of banana plantation workers regarding the socio-economic impact of Panamá disease. Data were gathered through face-to-face individual interviews. The analysis of the data was conducted using the Statistical Package for Social Sciences (SPSS) version 15 (SPSS Inc, 2006), and path analysis was performed using AMOS Graphics 7 (Hair et al., 2005; Knoke et al., 2002).

Estimation

For testing the hypotheses (H1 - H4) on wellbeing, an index (Y) was constructed from 3 variables measuring the level of satisfaction with: *finances, activity and leisure* (Ahn et al., 2004) using a linear numeric scale of equal intervals with *1 = Very dissatisfied, 2 = Somewhat dissatisfied, 3 = Dissatisfied, 4 = Satisfied, 5 = Very satisfied and 6 = Fully satisfied*. The estimated *Cronbach's alpha value of 0.650* for the 3 variables, was fairly adequate (Kerlinger and Lee, 2000).

A multiple regression was performed to estimate the effects of explanatory variables on ex-employees' satisfaction with well-being (Y) represented by the following multiple regression equation:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + e$$

Where, b_0 = constant score of satisfaction with well-being independent of activity, monthly income, compensation, and years of unemployment, b_1 = change in score of satisfaction with well-being associated with unit change in activity, b_2 = change in score of satisfaction with well-being associated with unit change in monthly income, b_3 = change in score of satisfaction with well-being associated with unit change in compensation, b_4 = change in score of satisfaction with well-being associated with unit change in years of unemployment, *e* = prediction error (residual).

Explanatory variables (X_1, X_2, X_3, and X_4) are presented in Table 2. The study tested a causal model for perceptions of food quality consumed by ex-employees of the impacted banana plantation, based on six causal propositions about the relationship among five variables, namely monthly income (I), agricultural activity (A), satisfaction activity (SA), satisfaction finances (SF) and food consumption (FC), measured using a five point interval scale with *1 = Very bad, 2 = Bad, 3 = Reasonable, 4 = Good, and 5 = Very good.*

P1 (I-FC): *High amount of income increases positive food consumption perception.* Income provides households with physical access to food through purchasing food needed to satisfy their dietary needs and food preferences, and households with higher income are more likely to be food secure than households with lower income. Therefore, a positive correlation between level of income and positive assessment of quality of food consumption can be expected.

P2 (I-SA): *High amount of income increases satisfaction with current activity.* Satisfaction with current activity is influenced by the amount of income obtained by ex-employees.

P3 (A-SA): *Ex-employees have low appreciation of agriculture as the main livelihood activity*. Therefore, a negative correlation between activity and satisfaction with activity can be expected.

P4 (A-FC): *Agriculture limits perceptions of food consumption.* Families can consume their own produced food, but other livelihood significant influence on the household food security compared to farm income. Therefore, a negative correlation between agriculture activity and positive assessment of food availability can be expected.

P5 (SA-SF)*: Satisfaction with current activity increases satisfaction with finances.* Former workers satisfied with their current activity are likely to be satisfied with financial situation.

P6 (SF-FC)*: Satisfaction with finances predisposes positive assessment of quality of food consumption.* Financial satisfaction is directly related to amount of income, and this contributes to food availability and consumption, therefore a positive correlation between satisfaction finances and positive assessment of quality of food consumption can be expected.

Figure 5 displays the hypothesized causal relations among the five variables. Monthly income (I) and agricultural activity (A) are exogenous variables in the model. Satisfaction activity (SA), satisfaction finances (SF) and food consumption (FC) is endogenous variables. eAc, eFo and eFi represent the error terms indicating unknown causes of unemployed perception of quality of

Table 2. Description of explanatory variables.

Variable name	Level of measurement	Description
Activity (X_1)	0 = Non-agricultural 1= Agricultural activity	Current activity
Monthly income (X_2)	0 = Less than 3,000 MZN 1 = More than 3,000 MZN	Monthly income with current activity
Compensation (X_3)	0 = Less than 20,000 MZN 1 = More than 20,000 MZN	Money (benefits) received to compensate for job lost
Unemployment duration (X_4)	Number of years	Period without formal/contract work

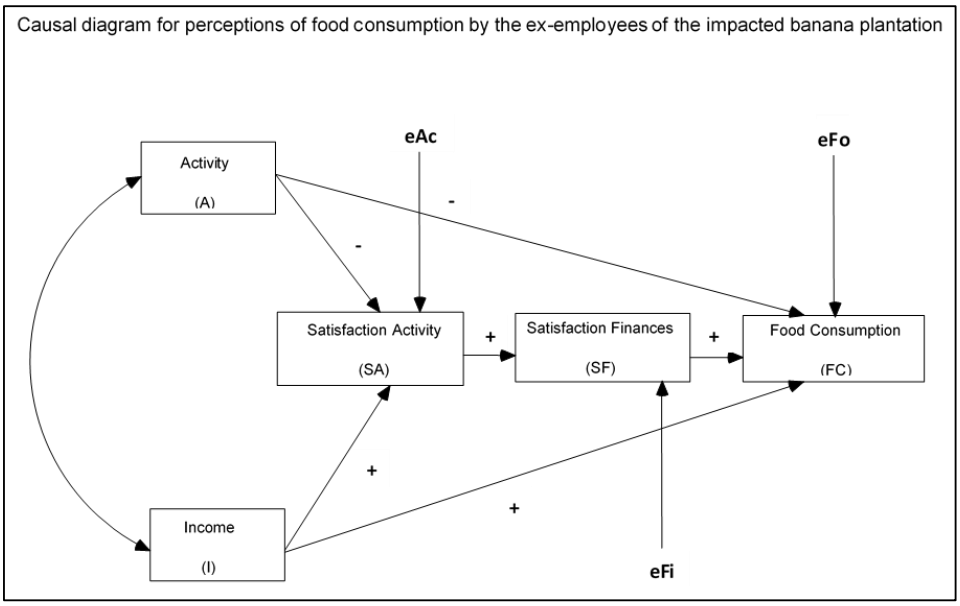

Figure 5. Hypothesized causal relations among exogenous and endogenous variables for food consumption perception.

food consumption. The following are the structural equations that represent the structure of interrelated hypotheses in the model:

Equation 1**:** Capture the hypothesized effects of income and activity on level of satisfaction with activity

$SA = P_{SAA}A + P_{SAI}I + P_{SAeAc}\,eAc$

Equation 2: Capture the hypothesized effects of satisfaction with strategies such as off-farm income, revealed to have strongest activity on satisfaction with financial situation.

$SF = P_{SFSA}SA + P_{SFeAFi}\,eFi$

Equation 3: Capture the hypothesized effects of income, activity, satisfaction with activity and satisfaction with financial situation on perception of quality of food consumption.

$FC = P_{FCA}A + P_{FCI}I + P_{FCSF}SF + P_{FCeFO}eFo$

Measures of goodness of Fit

Measures of goodness of fit indicated that the model fits fairly well the data. X^2 equals 8.055, *df* equals 3, P ≤ .045 and CMIN/DF equals 2.685 and is less than a cutoff of 5. Other measures of goodness of fit (CFI and RMSEA) which are independent of sample size indicated a good fit. The comparative fit index (CFI) had a value of .969, which is close to 1.

The root mean square error of approximation (RMSEA) also exhibited a value of .078 which is below the cutoff of 0.10. Similar values of the above measures of goodness of fit indicated were also reported by Hair et al. (2005) for samples higher than 250, number of observed variables less than 12.

RESULTS AND DISCUSSION

Occurrence of Panamá disease in banana production areas and the level of small holder farmers' awareness of Panamá disease

Incidence of Panamá disease in affected areas

The results showed the occurrence of the fungus *F.*

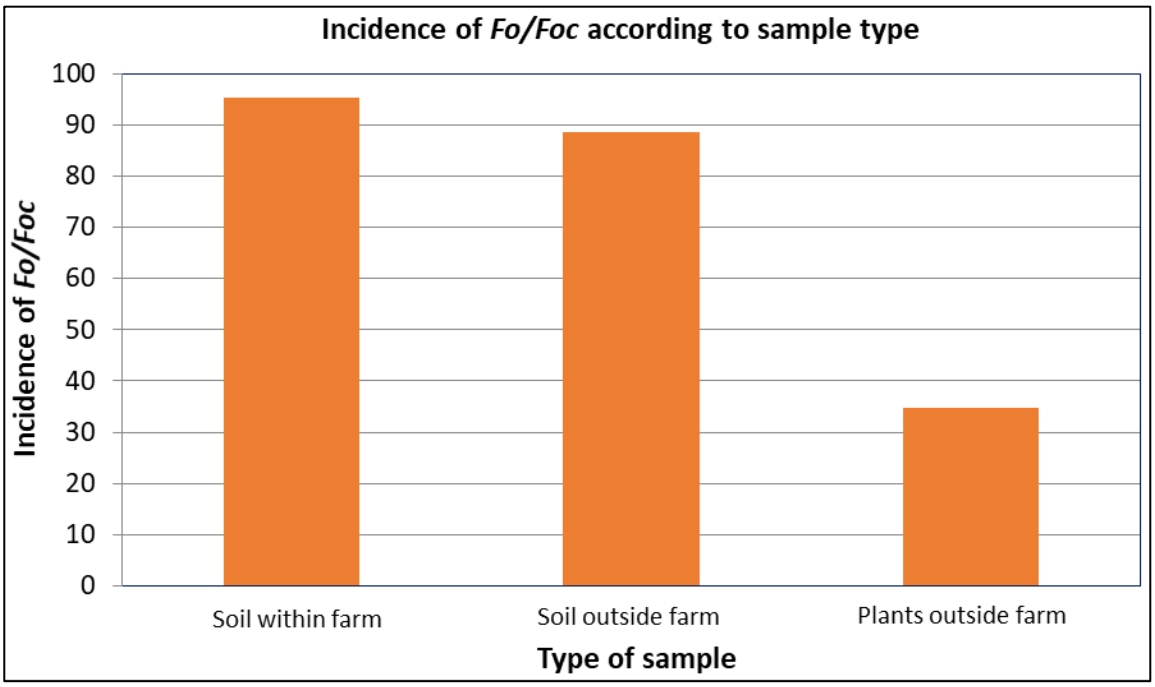

Figure 6. Incidence of *F. oxysporum /Foc.*

oxysporum (Fo) in both soil samples, that is, inside (96%) and outside the farm (89%). In plants, about 34% samples showed the growth of *Fusarium oxysporum f.sp. cubense* (*Foc*) (Figure 6). In the soil samples, there was a trend towards a higher incidence of the fungus in the soil collected inside the farm, a place widely known to be infested.

Based on the morphological characteristics of the mycelium and spores, it can be concluded that both soil and plant samples were infested by the fungus *F. oxysporum*. Pure cultures obtained from soil samples collected inside and outside the banana plantation farm indicated the presence of the fungus *F. oxysporum* in the soil. However, it is challenging to morphologically distinguish *Foc* TR4 within the species. According to Dita et al. (2010), *F. oxysporum* naturally occurs in the soil as a saprophyte or antagonist. Different formae speciales of *F. oxysporum* can cause diseases in various crops. Confirming the presence of *Foc* TR4 in the soil or plants surrounding the banana plantation farm requires the PCR molecular test (Dita et al., 2010; Pérez-Vicente et al., 2014).

For plant samples, particularly those showing Panamá disease symptoms associated with pure cultures, the presence of *Foc* was confirmed, but TR4 could not be distinguished based on symptoms alone. However, considering other studies (Van Westerhoven et al., 2023; Viljoen et al., 2020) that conducted PCR tests in the same site and confirmed the presence of TR4 within the affected farms and surrounding areas, it is highly likely that the plant samples were infested by *Foc* TR4.

Current distribution of Panamá disease in affected areas

The map (Figure 7) illustrates the spatial distribution of Panamá disease in the surroundings of the plantation farm. However, there is a trend towards greater disease intensity in the Metocheria community (northern part of the plantation), which is the closest populated area to the farm.

The occurrence of *Foc* in the regions surrounding the plantation farm is an aspect to be taken into account in mitigating the spread of the Panamá disease. Corroborating with Pérez-Vicente et al. (2014) in the present study, some forms of dissemination were found that could favor the dispersion of *Foc* TR4 to the surrounding regions of the farm, such as the invasion of the farm by the surrounding population through the violation of the fence, the percolation of water through sloping areas from the inside to the outside of the farm, the movement of propagating material and soil from inside the farm to surrounding areas by farm workers, the movement of people and vehicles into and out of the farm. On the other hand, the inappropriate felling of infested banana trees in surrounding areas could spread the disease to other regions.

Factors of pathogen dispersal and small producers awareness of Foc TR4

Anthropogenic factors contributing to the spread of *Foc*

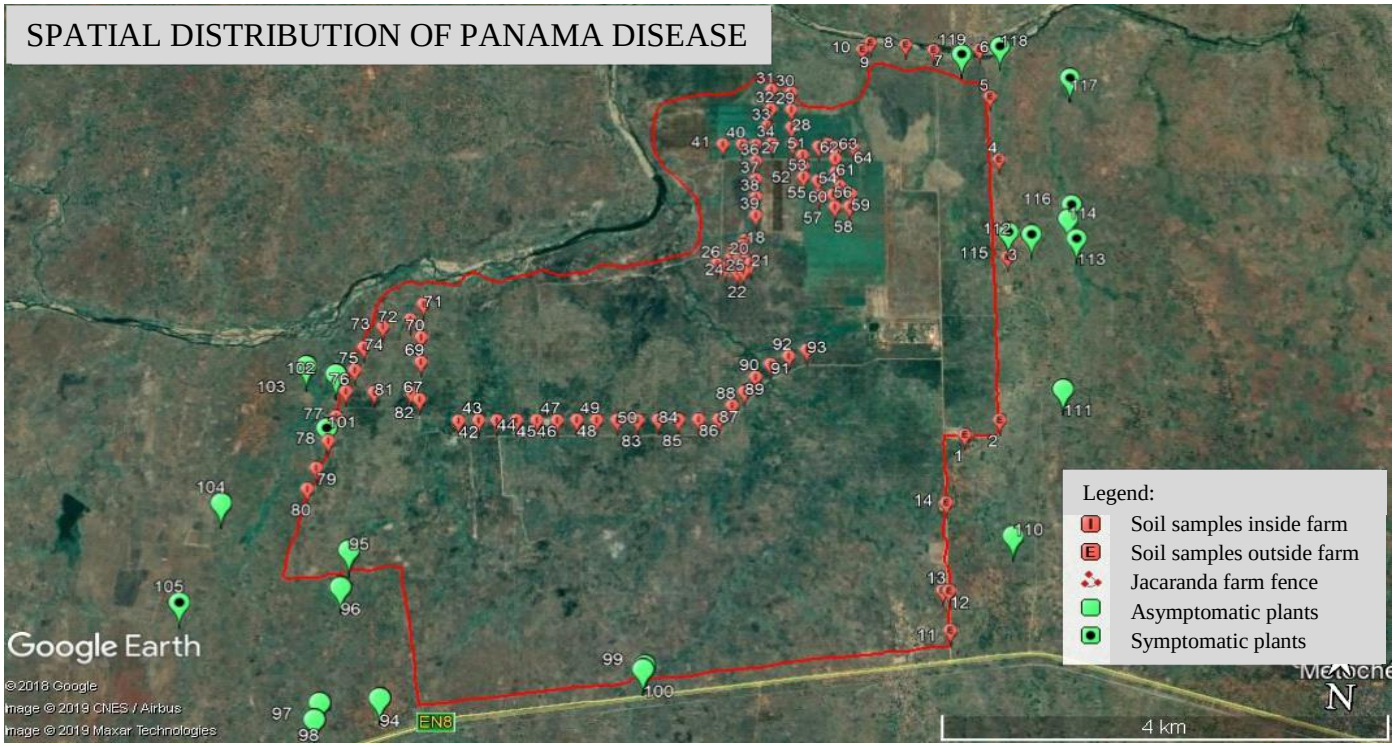

Figure 7. Map of current distribution of Panamá disease in affected areas.

TR4 (Dita et al., 2018) were observed and included the invasion of the affected banana plantation to collect firewood and other wood materials for construction, movement of seedlings and soil from the interior of the farm to surrounding areas, and a low level of awareness of Panamá disease management among small producers. Approximately 50% of small producers reported being located, on average, 17.78 km from the infected farm and were not aware of Panamá disease. Additionally, 49.8% were located, on average, 3.93 km from the infected farm and reported some basic knowledge about the disease. Among the farmers reporting knowledge of Panamá disease, the majority (77.2%) expressed that "the disease attacks the banana plant and kills it," 17.5% reported that "the attacked plant turns yellow and dies," and a small proportion of producers (5.3%) could not articulate any specific aspect of Panamá disease. Neighbors and friends were the major source (59%) of information on Panamá disease, followed by the workers of the infected banana plantation (41%). All 124 producers interviewed reported not knowing about Panamá disease management and did not receive extension technical assistance for banana production. The proximity of the community of Metocheria (less than 100 km) to the plantation farm, the low awareness of Panamá disease and its management among small producers, associated with the greater intensity of Panamá disease in Metocheria, indicate high potential for the dispersion of *Foc* TR4 and the risk of contamination from inside the farm to the outside, and to other more distant regions. Low awareness of Panamá disease, in particular, indicates a weak capacity for very early recognition of the disease (Pegg et al., 2019).

Perceptions of the unemployed on the magnitude of negative socioeconomic impact of Panamá disease

General characteristics of the unemployed

Table 3 presents the profile of ex-employees of the impacted banana plantation. The study interviewed 272 unemployed individuals, with an average age of about 38 years, who were heads of families with an average size of 6 members; including children aged 0 to 5 years. The majority (56.2%) of ex-employees reported being unemployed for 1-2 years and 93% engaged in agricultural activity as their main means of livelihood, but only 3.7% reported consumption from their own production. About 7% reported engaging in other activities such as small business, carpentry, construction, and transportation. Approximately 84% of the unemployed reported a monthly income of less than 3,000 MZN, and 66.9% had received compensation of more than 20,000 MZN. About 55% reported low job prospects. The unemployed also reported a lower average monthly

Table 3. Characteristics of ex-employees (unemployed) of the impacted banana plantation.

Characteristics	Ex-employees of impacted banana plantation	
	Frequency	%
Age (years)	(n = 272)	
Less than 30	65	23.9
30 to 40	101	37.1
41 to 50	80	29.4
51-59	26	9.6
Gender	(n = 272)	
Male	187	68.8
Female	85	31.2
Monthly income (MZN)	(n = 272)	
Less than 3,000 MZN	253	93.0
More than 3,000 MZN	19	7.0
Quality food consumption	(n = 272)	
Bad	234	86.0
Good	38	14.0
Main activity	(n=272)	
Agriculture (small –scale)[1]	227	83.5
Non-agriculture	45	16.5
Main source of food	(n=272)	
Own production	10	3.7
Others (purchase)	262	96.3
Years of unemployment	(n=265)	
1-2 years	149	56.2
3-5 years	107	40.4
More than 5 years	9	3.4
Amount of compensation (MZN)	(n=266)	
Less than 20,000 MZN	88	33.1
More than 20,000 MZN	178	66.9
Job prospects within a year	(n=266)	
High	83	31.2
Low	147	55.3
No expectations	36	13.5

[1] Maize, cassava, cotton, sesame

Income (2,094.74 MZN) than the employees (5,043.42 MZN), and the difference was statistically significant ($p<.05$). The results indicated that the majority of the unemployed were in their active working age, unemployed for a long period (that is, > 6 months) (Lindsay et al., 2003), and engaged in agriculture as the main livelihood activity (Mutea et al., 2019). Nevertheless, agriculture provided low monthly income, with an average monthly income of 2,094.74 MZN. This amount of income was 37% less than the average salary of 3,325.25 MZN they received while working on the banana plantation and is much lower (58%) than the 5,043.42 MZN, the average salary of current banana plantation employees. Reduced income is an immediate consequence of unemployment, as found in other studies (Pérez-Vicente et al., 2014; Ahn et al., 2004). The perceived differences between the

Table 4. Well-being satisfaction of unemployed and employed.

		Activity		Finances		Leisure	
		Unsatisfied	**Satisfied**	**Unsatisfied**	**Satisfied**	**Unsatisfied**	**Satisfied**
Unemployed	n	237	35	256	16	181	91
	%	87.1	12.9	94.1	5.9	66.5	33.5
Employed	n	31	48	43	36	18	61
	%	39.2	60.8	54.4	45.6	22.8	77.2

Chi-square = 77.770, 76.407, 47.747 and P<.001.

amount of farm incomes and the income the unemployed would receive if they were working for the plantation might have contributed to an increase in the level of dissatisfaction with their current activity. The main characteristics of the ex-employees, and in particular, the reduced income they experienced, indicate a pressing need for employment. The plantation farm could consider contracting some of the ex-employees to recover production using tolerant varieties to Foc TR4, under conditions of quarantine and the application of biosecurity measures.

Well-being differences between the unemployed and the employees

Table 4 presents the levels of satisfaction of the unemployed and employees with their well-being. The unemployed were more dissatisfied (P<.001) than the employees with their well-being. Dissatisfaction among the unemployed was particularly notable in the financial situation (94.1%) and the main activity (agricultural activity) currently developed (87.4%). The majority of the employees were satisfied (60.8%) with their activity at the plantation but unsatisfied (54.4%) with the financial situation. Regarding leisure time, the majority (66.5%) of the unemployed reported dissatisfaction, while the employees (77.2%) reported satisfaction with leisure time.

The unemployed experienced substantial reductions in satisfaction with their well-being, particularly with their main activity and financial situation. These results support existing findings that the unemployed usually report significantly lower well-being scores than the employed. Previous research (Hoang and Knabe, 2021; Ahn et al., 2004) found substantial reductions in the satisfaction levels of the unemployed with their main vocational activity and finances. However, regarding leisure time, the results of this study indicated that rather than being greatly satisfied with leisure, as found by Hoang and Knabe (2021), Esche (2020), and Ahn et al. (2004), the majority of unemployed individuals from the banana plantation were unsatisfied with the amount of time spent in non-labor market activities, including family gatherings, attending church, or other social groups. The results suggest that ex-employees do not associate the free time resulting from not working at the plantation with leisure. Since the employed, with relatively higher incomes than the unemployed, are likely to spend more money during each hour of leisure (Ahn et al., 2004), substantial reductions in the income of the unemployed may constrain their leisure and enjoyable activities and increase their levels of dissatisfaction with leisure time. Additionally, despite job seeking being considered a leisure activity (Hoang and Knabe, 2021), the results show that job prospects among the unemployed were low (55.3%), indicating that the unemployed, somehow, did not associate the additional time spent in family gatherings, attending church, and other social groups with improving their capacity to look for a job.

Determinants of wellbeing satisfaction of the unemployed

Table 5 presents the determinants of well-being satisfaction for the unemployed. The level of satisfaction with well-being is influenced by monthly earnings and unemployment duration. Unemployed individuals earning a monthly income of more than 3,000 MZN experience an increase in well-being satisfaction by 0.684 (P<.05) compared to those earning less than 3,000 MZN, after controlling for the effects of other explanatory variables in the model. Regarding the impact of unemployment duration, an increase of 1 year reduces satisfaction with well-being by 0.123 (P<.05). This suggests that the longer an individual remains unemployed, the more dissatisfied they become with their well-being, even when accounting for the effects of other variables in the model. Monthly earnings are positively associated with the level of satisfaction with well-being, while the unemployment duration is negatively associated with it.

These results align with previous research that identified a linear association between income and an individual's satisfaction with their well-being, as well as the negative impact of unemployment duration on individual well-being (Ahn et al., 2004; Scheve et al., 2017). This suggests that individuals who are unemployed may not quickly adapt to their unemployment status, experiencing significant shocks to their well-being. In

Table 5. Determinants of wellbeing satisfaction of the unemployed.

Parameter	B	Std. error	t	Sig.
Constant	3.266	0.102	32.092	0.000
Activity	-0.075	0.084	-0.898	0.370
Income	0.684	0.137	4.983	0.000
Compensation	-0.073	0.063	-1.151	0.251
Unemployement duration	-0.123	0.024	-5.147	0.000

R-Square: 0.161 = 16.1%.

Table 6. Standardized regression coefficients for satisfaction activity, satisfaction finances and perception food consumption.

Independent variables	Satisfaction activity	Satisfaction finances	Perception food consumption
Monthly income	0.193**		0.237***
Agricultural activity	-0.104		-0.160**
Satisfaction activity		0.592***	
Satisfaction finances			-0.012

**P<.001, *** P<.0001, n=272.

such circumstances, adaptation to unemployment occurs at a slower rate, and the lengthening of unemployment exacerbates financial and emotional challenges. However, research also indicates that adaptation can occur in life events such as changes in income (Georgellis et al., 2008); suggesting that support for the unemployed could focus on improving adaptation to changes in income. This support may involve increasing job prospects and offering opportunities for alternative income sources, along with providing information on government and private sector programs or initiatives.

The causal model for perceptions of food quality consumed by the unemployed

Table 6 and the path diagram (Figure 7) present the standardized regression coefficients for satisfaction activity, satisfaction finances and perception food consumption. Figure 8 presents the path diagram for perceptions of food quality consumed by the unemployed.

Monthly income was positively associated (P<0.001) with levels of satisfaction with vocational activity and with Perception food consumption (P<0.0001). The largest direct effect of monthly income was on the perception food consumption, where one standard deviation increase in monthly income led to about a one-fifth standard deviation increase in the perception food consumption, that is, positive perception. Agricultural activity was negatively associated with Perception food consumption (P<0.0001). One standard deviation increase in agricultural activity decreased the scores of perception food consumption by 0.160 standard deviations, that is, negative perception). Satisfaction activity was positively associated with Satisfaction finances (P<0.0001). An increase of one standard deviation of satisfaction activity led to more than half standard deviation in Satisfaction finances. As expected, monthly income and agricultural activity as the main livelihood had significant direct effects on the perception of food consumption. The unemployed reporting monthly income above 3,000 MZN held positive perception on their food consumptions. They obtained their food from both own production and local market. Agriculture contributes to food availability; families can consume their own produced food, but other livelihood strategies such as off-farm income, revealed to have strongest significant influence on the household food security compared to farm income (Mutea et al., 2019). Income provides households with physical access to food through purchasing food needed to satisfy their dietary needs, and households with higher income are more likely to be food secure than households with lower income (Mutea et al., 2019). Agricultural activity as the main livelihood did not predispose the unemployed to formulate positive evaluations of their food consumption. The unemployed when associate their food consumption to agriculture as the main livelihood activity they perceive themselves and their families as facing difficulties for maintaining or improving the quality of food consumption (Tesfaye and Nayak, 2022), including dietary needs and food

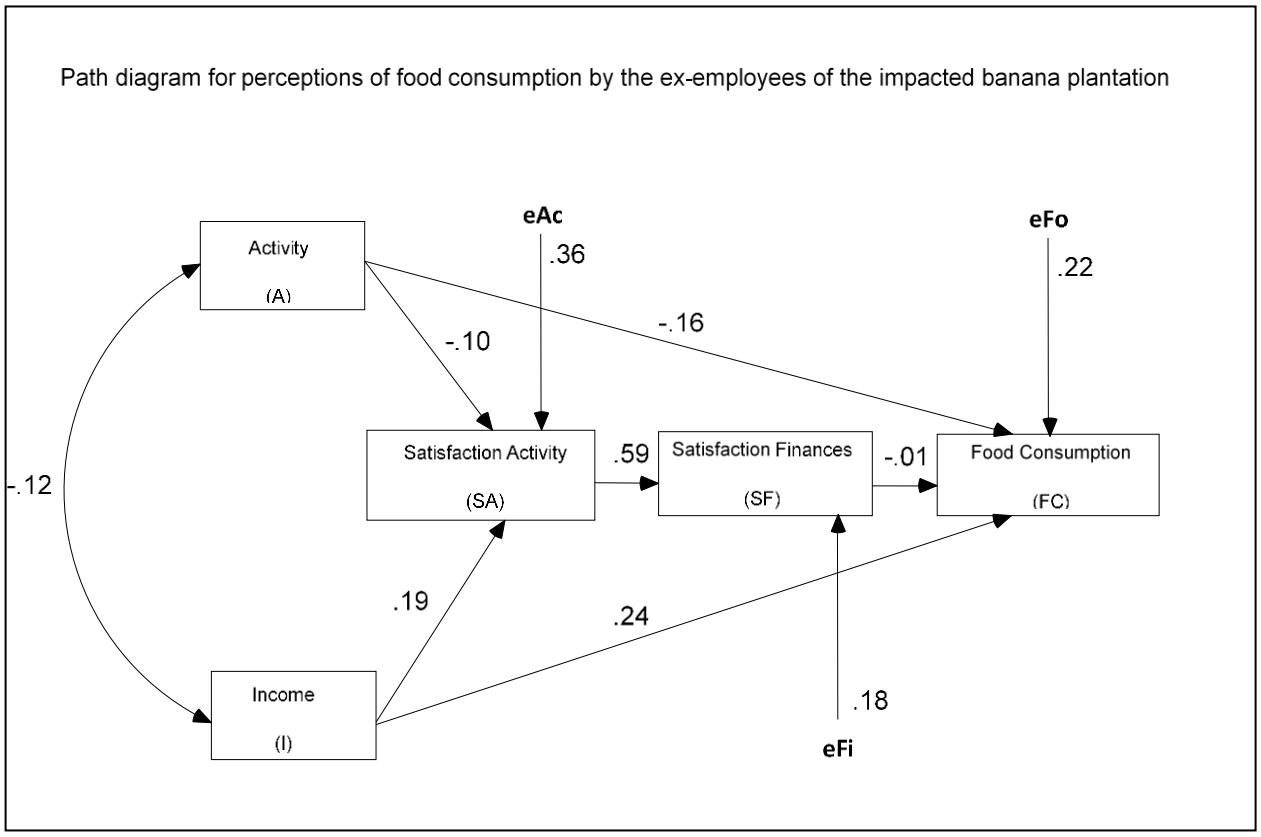

Figure 8. Path diagram for perceptions of food consumption.

preferences, they had when working for the banana company. Moreover, it is probable that the unemployed experience income effects in that, reduction in income decreases their purchasing capacity including of food items due to increase of the average cost of the diet relative to household income. The cost of a healthy diet is an indicator of economic access to nutritious foods and healthy diets, which is one of the core principles embedded in the definition of food security (FAO, IFAD, UNICEF, WFP and WHO, 2022). In 2019 the minimum wage in the agricultural sector was 4,142MZN. Small scale agriculture provides low and unstable monthly income but, 93% of unemployed developed agricultural activity as their main means of livelihood, and about 84% reported a monthly income of less than 3,000MZN. In these circumstances the unemployed could not be able to purchase the food basket to meet household's food needs. This impact could be directly affecting at least 2,000 families of the workers laid off and indirectly 12,000 people, including children aged 0-5 years, subject to malnutrition.

Conclusion

The occurrence of infected plants outside the plantation farm indicates the presence of *F. oxysporum* f. sp. Cubense in the surrounding regions. However, the confirmation of *F. oxysporum* f. sp. Cubense TR4 in the soil or plants outside the farm was hindered by the unavailability of the PCR molecular test during the study period. Other studies using PCR tests have confirmed TR4's presence in the surrounding areas, suggesting a high likelihood of *Foc* TR4 in plants outside the farm and confirming its spread. Small producers' practices, such as entering the affected areas for collecting firewood and moving seedlings and soil, likely contribute to Panamá disease spread. However, the awareness of *Foc* TR4 and its management is almost nonexistent among producers. Improving producers' knowledge can be achieved through agricultural extension programs focusing on an adaptive and integrated disease management approach involving resistant varieties, exclusion, biosecurity, and soil management to enhance banana production.

Unemployment emerged as a significant negative socioeconomic impact of Panamá disease, with dissatisfied ex-employees expressing notable dissatisfaction, particularly in financial situation and agricultural activity as the main livelihood. Agricultural activity failed to provide sufficient income for the unemployed families to purchase additional food items, prompting considerations for re-hiring some ex-employees

to contribute to new plantations and revive banana production. Local government initiatives disseminating information on job opportunities could further enhance job prospects for the unemployed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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