

This Commodity Focus is excerpted from the November 2019 edition of the  
FAO Food Outlook, published here:

<http://www.fao.org/3/ca6911en/ca6911en.pdf>

# COMMODITY FOCUS

# Banana Fusarium Wilt Tropical Race 4: A mounting threat to global banana markets?

## The recent spread and potential future impact of the disease on global banana trade

Sabine Altendorf<sup>1</sup>

[Sabine.Altendorf@fao.org](mailto:Sabine.Altendorf@fao.org)

Commercial banana production has been subject to intensive farming techniques since the late nineteenth century, with the emergence of large-scale trade from Central American and Caribbean banana producing countries to the United States and Europe. To cater for rapidly growing demand in mostly far distant import markets, producers identified the *Gros Michel* variety as the most suitable for monoculture propagation and long transport routes. By 1955, the global export volume of bananas from Central American producers had reached approximately 3 million tonnes, making bananas the most exported fresh fruit globally – ahead of citrus fruits and apples – at a volume share of 40 percent in world fresh fruit trade.<sup>2</sup>

The Fusarium wilt disease of banana, scientifically denominated as *Fusarium oxysporum* f. sp. *cubense* and considered among the most destructive of all plant diseases, was first detected in banana plantations in Australia in 1876.<sup>3</sup> The first large-scale outbreak in export plantations was subsequently reported in 1890 in Panama. A soil-borne pathogen, the mycelium and spores of *Fusarium* wilt spread through: infected plants and planting materials; soil particles attached to shoes, vehicles and tools; water, including irrigation, drainage and floods; as well as other physical means of spread. Facilitated by the monoculture and intensive plantation cultivation techniques and concentrated transport routes of the commercial banana industry, by the mid-1950s, this first strain (Race 1) of *Fusarium* wilt had caused such enormous damage to the production of *Gros Michel* that the export industry was forced to switch its entire production to the *Fusarium* wilt-resistant *Cavendish* variety. Official data suggest that total losses to trade in *Gros Michel* bananas at the time

amounted to a current equivalent of USD 2.3 billion.<sup>4</sup> Given the decades-long persistence of the *Fusarium* wilt fungus in the soil, *Gros Michel* bananas continue to be practically absent from world export markets to this day.

### TROPICAL RACE 4 – A RENEWED CHALLENGE TO GLOBAL BANANA SUPPLY

The current strain of the Banana Fusarium Wilt disease, described as Tropical Race 4 (TR4), was first discovered in 1970 in *Cavendish* banana plantations in Taiwan, and then on a more severe scale in *Cavendish* plantations in Indonesia and Malaysia in 1992/93. By the early 2000s, TR4 had spread to Australia, Papua New Guinea, China and the Philippines. In 2013, TR4 was discovered on farms in northern Mozambique and in Jordan, and in 2015 it emerged in Lebanon, Oman, India and Pakistan. Between 2017 and 2019, TR4 was found in Laos, Viet Nam, Myanmar and Thailand. In August 2019, the fungus was detected for the first time on a banana plantation in Latin America, in the northeastern region of La Guajira, Colombia. According to official information, TR4 is currently confirmed in 17 countries, predominantly in South and Southeast Asia.<sup>5</sup> This fourth race of the fungus poses particularly elevated risks to global banana supplies, as it can affect a much broader variety of banana and plantain cultivars than previous strains of *Fusarium* wilt.<sup>6</sup> In addition, there is currently no effective fungicide or other eradication method that is capable of eliminating TR4. In affected plants, the disease can quickly cause a total yield loss. Due to the longevity of the fungus in the soil, infected land becomes unavailable for banana or any other cultivation for decades, resulting in a shift of production to new,

<sup>1</sup> The author extends sincere thanks to Dr Charles Staver, Dr Altus Viljoen, Dr Diemuth Pemsli, Dr Lorna Herradura, Dr Randy Ploetz, Dr Tony Pattison and Dr Luis Pérez Vicente for their expert inputs on the probable spread of the disease.

<sup>2</sup> May *et al.* (1958)

<sup>3</sup> Ordonez *et al.* (2015)

<sup>4</sup> FAO (2019)

<sup>5</sup> FAO (2019)

<sup>6</sup> Ploetz (2005)

unaffected land as the only recourse. Depending on the severity of the spread, outbreaks can result in an increasing scarcity of pathogen-free soils. In all reported cases, once a farm has been contaminated, managing the disease has proved extremely challenging and costly. This poses a particular threat to the livelihoods of smallholder banana producers in affected regions, who often lack the financial means to sustain operations in the face of simultaneous yield losses and increased production costs. In this regard, prevention, rapid containment and quarantine are particularly important.

Given the serious implications for infected farms, precise and complete documentation of the damage caused by TR4 is often unavailable. In the worst cases of disease management, farms are abandoned without reporting and without being adequately quarantined, further impeding rapid containment of the disease. While no global estimates are available, figures for some countries indicate that the disease has affected around 15 700 hectares (ha) of banana plantations (out of a total 440 000 ha) in the Philippines,<sup>7</sup> and some 70 percent of plantations in China's Guangdong and Hainan provinces.<sup>8</sup> Annual economic losses caused by TR4 have been estimated at USD 121 million in Indonesia, USD 253 million in Taiwan and USD 14 million in Malaysia.<sup>9</sup> On the infected farm in Mozambique, TR4 caused such severe damage to the 1,500-ha plantation within 4 years of the first detection of the disease that the farm was forced to cease operations.<sup>10</sup>

## BANANA MARKETS IN THE PRESENCE OF TR4 – SUPPLY SHORTAGES AND HIGHER PRICES BY 2028?

The very recent discovery of *Fusarium* wilt TR4 in the world's most significant net exporting region, Latin America and the Caribbean, as well as its enduring occurrence in Asia, has caused considerable alarm in the banana export industry. To date, few estimates of the additional disease-related costs to producers are available. However, industry experts believe that, given the current annual value of production for export and the importance of *Cavendish* bananas for smallholders, it is possible that TR4 will eventually cause even greater losses than the original strain of *Fusarium* wilt that affected the production of *Gros Michel* bananas.

<sup>7</sup> The Southern Mindanao Agriculture, Aquatic and Natural Resources Research and Development Consortium, as quoted by Freshplaza, 10 March 2016.

<sup>8</sup> Chen *et al.* (2013)

<sup>9</sup> Aquino *et al.* (2013)

<sup>10</sup> Altus Viljoen, Stellenbosch University, South Africa

To assess the potential future impacts of TR4 on global banana markets, a partial equilibrium commodity market model covering national and international banana markets was used. The model adopts the basic specifications for supply, demand, trade and prices of FAO's commodity simulation model (COSIMO), which is used to generate ten-year projections for global temperate agricultural commodities on an annual basis. The underlying assumptions of the model concerning the global economic and demographic projections follow those outlined in the OECD-FAO Agricultural Outlook published in July 2019.<sup>11</sup> The scenario presented herein regarding the hypothetical market impact of TR4 provides suggestive rather than predictive impact results, which should not be interpreted as actual forecasts, but rather as an indicative basis for informing policy decisions.

The time span for the simulation analysis covers ten years, from 2019 to 2028, to enable a direct comparison with the baseline projections, which were produced in May 2019. These were based on 'business-as-usual' assumptions, foreseeing normal weather, no changes in policy, and in particular no changes in the prevalence of crop diseases. Under the baseline projections, global banana production will grow at an annual rate of 1.5 percent over the ten-year period, to reach approximately 135 million tonnes in 2028. Global trade in bananas is projected to grow at a moderate rate of 1 percent per year due to slowing demand in large developed country import markets, where consumption is forecast to reach near saturation levels.

As mentioned above, the framework underpinning the assessment of the possible impacts of TR4 on global banana markets is a standard multi-commodity, multi-country partial equilibrium model. The scenario analysis was adapted from a similar approach used by *Acquaye et al.* (2005), who conducted an evaluation of the economic consequences of an invasive species outbreak for a large-country exporter applied to the case of Citrus Canker. The results of the model are contingent on the stylized assumptions of perfect competition and homogenous world markets for bananas. In this regard, the model deviates somewhat from the observed reality of global banana markets, which may display regional fragmentation and oligopolistic behaviour by large, dominant banana corporations. However, the fundamental conclusions reached by the analysis are consistent with those of alternative model specifications. For example, an uncontained spread of TR4 in fragmented markets would lead to higher prices and larger economic losses to either

<sup>11</sup> [www.doi.org/10.1787/agr\\_outlook-2019-en](http://www.doi.org/10.1787/agr_outlook-2019-en)

## Box: Bananas in food security and world markets

Bananas represent one of the most consumed and traded fruits globally. In many developing countries, bananas, along with their subcultivar plantains, serve as a staple food that is included in many forms in local diets. While precise statistics on consumption remain sketchy due to the informality of subsistence cultivation in many regions, Filipinos reportedly have the highest per capita consumption of dessert bananas at around 60 kg per year, followed by Brazilians who consume a slightly lower amount. In some African countries, such as Angola and Rwanda, per capita consumption of all dessert and cooking banana types combined exceeds 200 kg per year. Particularly in the rural areas of these countries, bananas can provide up to 25 percent of daily calorie intake.<sup>1</sup> In tandem with the increase in the world population to more than 7 billion people, global banana production expanded from 21 million tonnes in 1961 to approximately 114 million tonnes in 2017. According to some estimates, more than 100 billion bananas are now consumed worldwide each year.<sup>2</sup> The main driver of this rapid rise in production has been the increasing consumption requirements of the growing populations in developing countries. The bulk of the global production increase has taken place in top producing countries who are also top consumers, such as Brazil, the Philippines and, in particular, India and China. The total value of global production stood at an estimated USD 38.5 billion for bananas and USD 6.6 billion for plantains in 2016.

In addition, bananas have particular significance in some of the least developed and low-income food-deficit countries, where they contribute not only to household food security as a staple, but also to income and employment generation as a cash crop. At farmgate prices of around USD 300-400 per tonne and typical smallholder yields of 10-15 tonnes per hectare, bananas can generate an estimated USD 3 000 to 6 000 per hectare per year. Research conducted in 10 banana producing countries revealed that revenue from banana farming can account for some 75 percent of total monthly household income for smallholder farmers.<sup>3</sup> It is further estimated that approximately 400 million workers rely on income from direct employment in the banana industry globally.<sup>4</sup>

Bananas play a similarly important role in developed country importing markets, where they have ranked among the most consumed fruits for decades. This is reflected in the noticeable performance of the global banana export market, which reached an unprecedented 19.2 million tonnes in 2018. Preliminary data for the first half of 2019 suggest that global trade in bananas expanded by a further 11 percent over the same period of the previous year. Ample import demand in developed markets, combined with strong yield-driven supply growth in the leading exporting countries, have been the principal factors behind this increase.

Globally, Latin America and the Caribbean ranks as the largest banana exporting region, accounting for nearly 80 percent of world exports. Ecuador has been positioned as the world's leading exporter over the past several decades, supplying an average of 5 to 6 million tonnes to world markets per year. In 2018, Colombia ranked as the fourth leading exporter globally with a total volume of 1.7 million tonnes, equivalent to approximately 9 percent of global exports. Asia, the second largest supplier of bananas for export, accounted for approximately 20 percent of global shipments in 2018, almost entirely supplied by the Philippines, the dominant exporter in the region. In terms of leading importers, the European Union and the United States absorbed, respectively, approximately 32 percent and 26 percent of total global supplies in 2018. The Russian Federation, China and Japan are also significant importers, albeit with single-digit market shares in 2018.

Given the popularity of bananas in import markets, their global value chains have been characterized by intense competition between market actors all the way to the retail level. This has exerted downward pressure on prices at each stage, which resulted in producer prices displaying little fluctuation and, by and large, remaining at very low levels. Combined with rising production costs, low prices and tight profit margins greatly hinder the adequate remuneration of banana workers and smallholder farmers and act as a major obstacle for producers in coping with emerging challenges, in particular the looming threat of TR4.

<sup>1</sup> FAOSTAT

<sup>2</sup> Bananalink, <http://www.bananalink.org.uk/all-about-bananas>

<sup>3</sup> Bioversity (2012)

<sup>4</sup> FAO (2019)

producers or consumers in the respective regional producing and trading countries. Similarly, relaxing the assumption of perfect competition would lead to larger world price increases, as oligopolistic behaviour would extract rents from markets that are short in supply.

The scenario is further based on potential TR4 spread rates and losses in harvested area in key banana producing countries, which are provided in a CGIAR working paper by Scheerer *et al.* (2018). The paper presents two spread and loss scenarios, which are constructed from a base probability of infection that hinges on the prevalence of *Cavendish* monoculture in a producing country, as well as internal geographical, phytosanitary, transport and other factors.<sup>12</sup> The high spread scenario assumes an internal disease spread at a rate of 50 percent in five-year time intervals up to 25 years. For the current study, the estimated internal spread and impact on area in the lower loss scenario presented by Scheerer *et al.* (2018) was chosen, which anticipates incremental increases in losses of 25 percent every five years. It should be noted that the estimated internal spread rates show the area losses due to TR4 to be increasing over time, indicating that the disease impacts over a period beyond the ten years chosen for this scenario would be amplified. Furthermore, although TR4 can affect a broad variety of banana cultivars, the analysis presented in this assessment encompasses the possible economic impact on the *Cavendish* variety only, which is predominant in global trade and plays a significant role in income and foreign exchange generation for exporting countries.

Figure 1 shows the expected percentage of area loss to the production of bananas in 2028 due to TR4 infection for each of the countries for which estimates are provided. Weighted averages of the internal spread rates of the *Cavendish*, *AAA*, *Other AAA* and *EAH AAA* banana cultivars specified in the paper were calculated and applied to total FAOSTAT banana production data.<sup>13</sup> Scheerer *et al.* (2018) determine that the highest rates of spread will affect key producers in Asia, most notably China, the Philippines, Pakistan and Viet Nam, as well as Mozambique

<sup>12</sup> As Scheerer *et al.* (2018) explain, factors linked to the time lag for TR4 to reach a country include the importance of mono-cropped *Cavendish* bananas in the country; global banana traffic to and from a country; quality of borders and internal plant quarantine measures; and land and other links to countries where TR4 is currently present. The rate of internal spread was rated based on three factors: quality of internal quarantine measures; importance of *Cavendish* bananas; and the importance of banana for research investment and public policy. These two elements were then combined in an aggregated score that was used to estimate banana production area loss by country.

<sup>13</sup> For the case of India, Scheerer *et al.* (2018) assume an arrival of TR4 in the country after ten years. However, official information specifies that TR4 has been present in India since 2015. In the absence of estimates for the production area lost due to TR4 in the first ten years as otherwise adapted from

and Tanzania in Africa. At the time of writing, Scheerer *et al.* assumed a TR4 arrival time in Colombia after ten years. Considering the low score for the internal spread rate identified for Latin American and Caribbean banana producers, which results mainly from their superior internal plant quarantine capabilities, the area loss due to TR4 infection was assumed to amount to 1.25 percent of banana area in Colombia by 2028. Although neighbouring key banana producing countries are at elevated risk of contamination by TR4, most notably Ecuador, Peru, Brazil and Panama, the current scenario does not include a spread of TR4 outside the boundaries of Colombia. This was based on the absence of sound scientific assessments regarding the potential arrival of TR4 in those countries. Information gathered by the author from leading plant pathologists and banana experts pointed to the conclusion that assigning a rate of spread within Latin America and the Caribbean would at this stage be difficult and, moreover, highly speculative, given that any hypothetical spread may hinge on many unpredictable and virtually unmanageable factors. Similarly, it has proved difficult to pinpoint the precise costs of containment and prevention of TR4. As such, in the current scenario, production costs for both affected and unaffected countries have not been adjusted to reflect the numerous additional expenses arising from TR4 adaptation and mitigation. As more information becomes available, the scenario can be modified to reflect realistic estimates of these costs.

**Figure 1. Area loss after 10 years due to *Fusarium* wilt TR4 at 25 percent internal spread rate<sup>14</sup>**

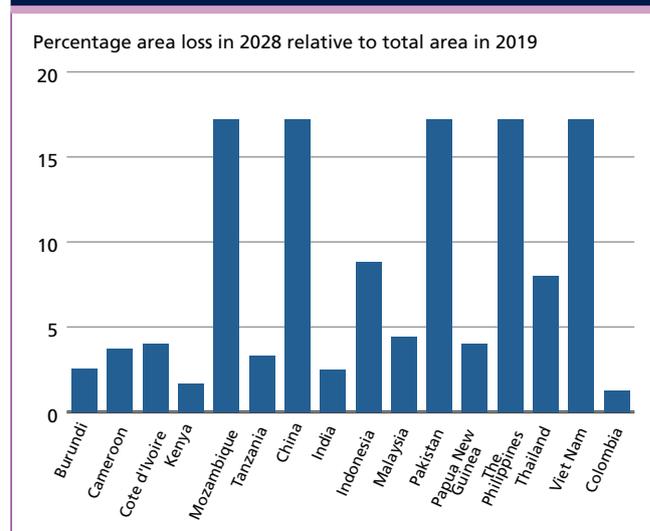
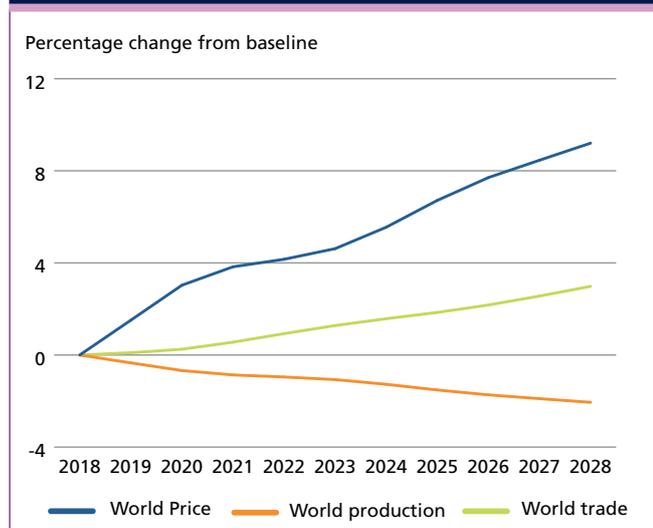


Table 7 in Scheerer *et al.* (2018), a moderate spread rate arriving at a loss of 2.5 percent of total area as indicated in Figure 2 of the same paper was chosen as indicative of a potential spread of TR4 in India.

<sup>14</sup> Adapted from Scheerer *et al.*, (2018)

For the current scenario, the banana area response equation of the model was shifted in linearly increasing steps from 2019 to 2028 in each of the countries for which data are provided, arriving at the assumed area losses by 2028, as displayed in Figure 1.<sup>15</sup> Compared with the baseline projection, this would lead to a loss of an estimated 160 000 hectares globally by 2028. Assuming an average of 1.5 workers per hectare, this would imply the loss of direct employment for approximately 240 000 banana workers. In terms of production volume, the area loss would result in a 2.8 million tonne or 2 percent reduction in global banana production by 2028. Since markets would ration reduced supply, the decline in world production would induce a 9.2 percent rise in the global reference price for bananas by 2028, contingent on the inelastic demand for bananas, which would cause prices to rise more than production would fall. As further illustrated in Figure 2, global trade, which would rise to partially compensate for shortages in domestic supply in affected producing countries, would increase by 3 percent over the baseline by 2028.

**Figure 2. Scenario impact on production, price and trade in the global banana market**



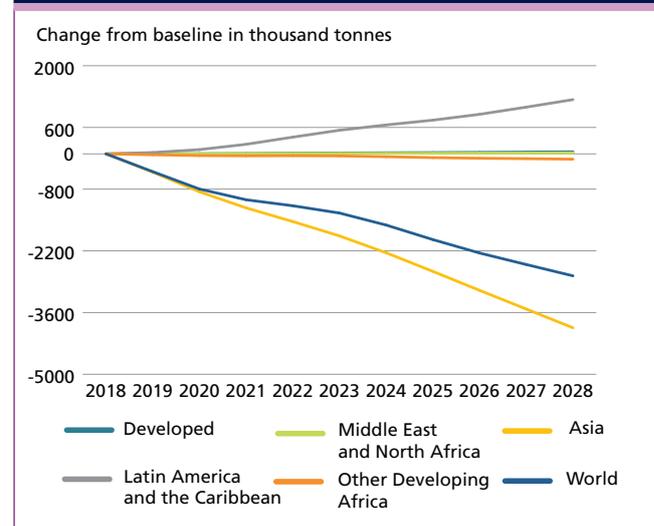
Looking at the potential impact on banana production by region, given the sizeable projected area losses in several Asian and Southeast Asian countries (Figure 3), aggregate losses would be most pronounced in Asia, amounting to an estimated 3.9 million tonnes in 2028 relative to the baseline. Again, because such substantial losses to the world market would result in a rise in the world reference price, producers in unaffected countries would receive

<sup>15</sup> The implementation of a linearly increasing rather than exponential disease spread, which may be more reflective of the actual disease spread, facilitates the projected area losses after ten years as provided by Scheerer *et al.* (2018).

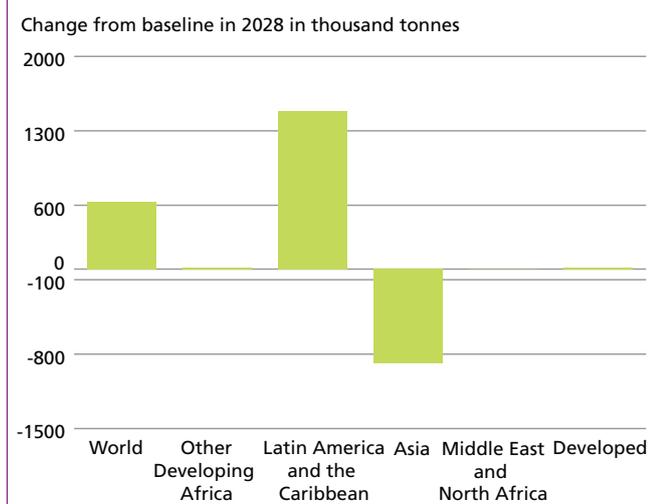
a stimulus to increase their production, thereby partially offsetting the losses incurred in Asia. Accordingly, the Latin America and Caribbean region, which is assumed to remain mostly unaffected by TR4 in the current simulation, is projected to produce 1.2 million more tonnes of bananas in 2028 than in the baseline scenario. Small increases in production over the baseline are also expected for banana cultivation in the developed country producers – notably in the European Union and South Africa – and in the Near East, which are similarly assumed to remain unaffected by TR4.

Globally, producer receipts would increase on account of significantly higher prices, more than offsetting lower production. Producers in unaffected countries would gain considerably under this scenario, particularly those in the highly exporting Latin American and Caribbean countries. However, in countries affected by TR4, banana producers would incur considerable losses. This would particularly apply to producers in China, Indonesia, Pakistan, the Philippines, Viet Nam and Mozambique, where future area and production losses are assumed to be greatest, translating into significant losses of gross incomes and employment in the banana sector in these countries.

**Figure 3. Scenario impact on banana production by region by 2028**

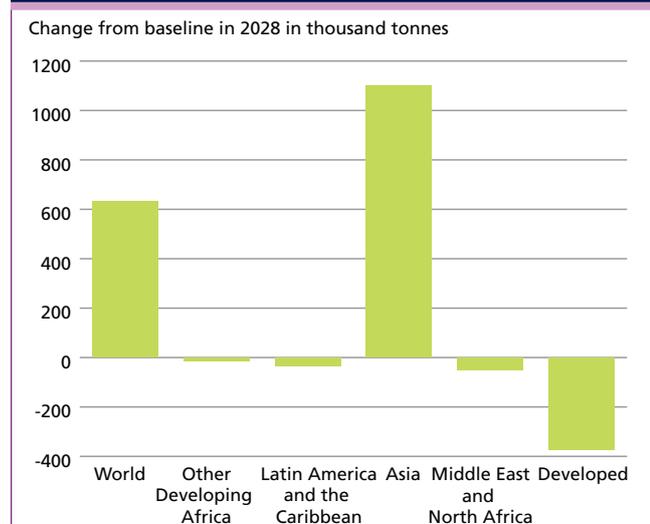


In terms of global exports, the shortage in supplies from Asia would, to some extent, be offset by increased exports from Latin America and the Caribbean (Figure 4). Compared with the baseline scenario, Asia would export 880 000 tonnes less per year by 2028, while the Latin America and Caribbean region would see its exports rise by 1.5 million tonnes, thereby further strengthening its dominance in world markets. On a net trade basis, i.e. when subtracting imports from exports, Asia would incur losses of approximately 2 million tonnes per year by 2028

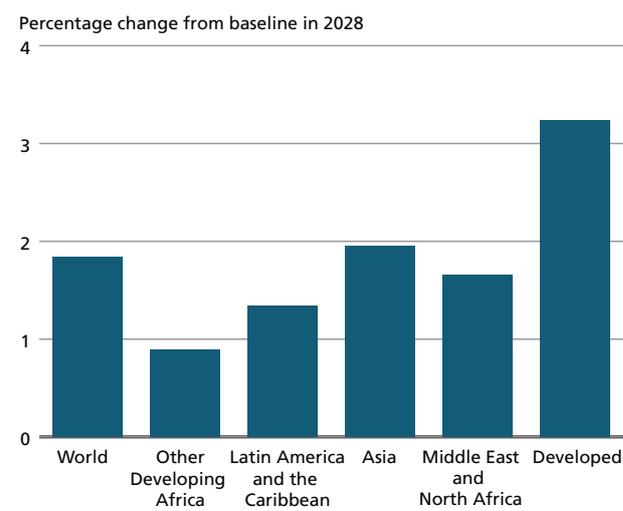
**Figure 4. Scenario change in banana exports by 2028**

under this scenario, highlighting the severely damaging consequences of an unabated spread of TR4.

As displayed in Figure 5, in order to satisfy internal demand, Asia would be obliged to import approximately 1.1 million tonnes per year more than it would have in the absence of TR4. Import prices in developed countries, the main importers of bananas, would meanwhile rise, resulting in an estimated volume reduction of 370 000 tonnes in 2028. In conjunction with elevated prices, the rise in exports from Latin America and the Caribbean would translate into considerably higher export revenues for suppliers from this region.

**Figure 5. Scenario change in banana imports by 2028**

On account of the resulting higher prices, the economic costs to consumers in all regions would increase (Figure 6). Globally, on average, while consuming almost a 2-percent lower volume of bananas, consumers would spend

**Figure 6. Percentage change in consumer expenditures on bananas by 2028**

1.8 percent more on bananas by 2028 than they would have under the baseline scenario. Regionally, the worst impact would be felt by consumers in developed country markets, where price elasticities for bananas tend to be comparatively low and price transmission high, resulting in a 3.2-percent increase from the baseline price by 2028.

The projections suggest that a further spread of TR4 would entail considerable loss of income and employment in the banana sector in the affected countries, at varying degrees contingent on the internal spread of the disease. Consumers in all countries with open markets would face rising costs due to higher prices, as market effects would transmit across borders. In affected producing countries, consumer costs could rise significantly as a result of possible border controls designed to protect domestic producers. Meanwhile, producers in unaffected countries would gain from the higher prices induced by the global area losses caused by TR4, and would additionally receive incentives to increase production. Unaffected exporting countries would, correspondingly, capture higher export revenues resulting from higher volumes of shipments at higher unit values.

## MITIGATING THE THREAT OF TR4

The simulation results suggestively illustrate the likely far-reaching repercussions that an unmitigated spread of TR4 would have on global banana markets. The underlying postulations of the simulation assume a low-spread scenario, implying that the potential impact on world banana supply and world banana markets could translate into significantly larger effects should the disease spread more rapidly or further afield. In particular, given the importance of the Latin America and Caribbean region in global banana exports, the specific outcome of the

impact on global markets would hinge on whether the recent outbreak of TR4 in Colombia can be contained or not. In the best case scenario, the disease would not spread further, resulting in no significant impact on global markets diverging from the projections presented here over the next decade.

In the worst case scenario, a wide spread of TR4 in Latin America and the Caribbean would have a considerable economic impact on trade, food security and the economic wellbeing of producing countries in the region, as well as on producers in other exporting countries and consumers in importing countries. The potential repercussions of infection by TR4 are of even greater concern to organic banana production, since organic agricultural practices do not permit genetic modifications, leaving classical breeding of disease-resistant cultivars as the only option for adaptation. This would be particularly alarming for the main producing countries of organic bananas that border Colombia, notably Peru and Ecuador.

In view of the wide-ranging potential ramifications on both conventional and organic banana markets, the recent outbreak of TR4 in Colombia necessitates elevated vigilance in the banana sector, not only in Latin America and the Caribbean, but also globally. The expertise of a leading plant pathologist suggests that future banana production may only become viable for growers who are able to implement more advanced management techniques and financially sustain significantly higher investments into disease prevention.<sup>16</sup> Governments of producing countries have a key role to play in mitigating the spread of TR4 and managing the disease where it has already emerged, particularly in view of its potential impact on smallholder banana farmers and workers employed in the industry. Close co-ordination of the capacity-development and extension activities of all concerned national institutions will be beneficial to the development of proper policies, regulations and strategic measures that address the challenges of TR4 in a comprehensive way. National support schemes drawn up in strategic collaboration with different stakeholders and designed to assist in the implementation of adequate biosecurity measures, as well as in the facilitation of diversified production systems that have shown to be less susceptible to TR4 infection than monocropping systems, may serve as responses that can alleviate the problem. Such compensating or support schemes may further contribute to containment of the disease, by easing the moral hazard problem of farmers not reporting and not treating infected plantations properly.

<sup>16</sup> Dr Charles Staver, Bioversity International, Montpellier, France

Markets and open trade display considerable potential to mitigate global economic costs of a greater spread of TR4, given the role of trade as a balancing force between supply and demand. As previously described, higher production in unaffected countries would largely compensate for lower production in affected countries. However, both national and global welfare costs can only be efficiently contained if open trade is maintained. Closing borders to trade would rapidly raise the economic costs of the disease in domestic markets. As such, those developed countries that are on a high net import position in banana trade would benefit from investing in research on TR4 prevention and mitigation, since the impact on consumers in developed country markets would be relatively high. Similarly, net exporting countries stand to benefit from investments in effective disease management strategies, as containment of disease spread will enable exporters to benefit from increased market access.

An assessment of the economic returns to four different banana research investments conducted by Scheerer *et al.* (2018) suggests that investments in integrated crop and disease management, as well as in the development of either conventional or genetically modified Fusarium-resistant banana cultivars, would yield the highest internal rates of return of the assessed options. The potential of Fusarium-resistant banana cultivars in managing epidemics of TR4 also seems evident in the progressive experiences with somaclone varieties on some commercial farms.<sup>17</sup> In conjunction with stringently imposed biosecurity measures, including early detection, effective eradication and on-farm quarantine, the planting of the partially TR4-resistant somaclonal *Giant Cavendish Tissue Culture Variants* appears to have significantly aided in counteracting losses from TR4. Recent advances in the development of fully Fusarium-resistant *Cavendish* varieties using chemical mutagenesis techniques or gamma radiation may offer an even more holistic solution to abating the threat from TR4.<sup>18</sup> Strengthened international collaboration, particularly with regards to enhanced data collection and information sharing, will further support improved awareness, prevention and containment of Fusarium wilt TR4 and be conducive to more resilient global banana production systems.

<sup>17</sup> [www.banana-networks.org/Bapnet/2016/02/22/fusarium-wilt-resistant-cavendish-cultivars/](http://www.banana-networks.org/Bapnet/2016/02/22/fusarium-wilt-resistant-cavendish-cultivars/)

<sup>18</sup> [www.iaea.org/newscenter/news/iaea-fao-help-develop-bananas-resistant-to-major-fungal-disease](http://www.iaea.org/newscenter/news/iaea-fao-help-develop-bananas-resistant-to-major-fungal-disease)

## REFERENCES

- Acquaye, A. K. A., Alston, J. M., Lee, H. & Sumner, D. A.** 2005. Economic Consequences of Invasive Species Policies in the Presence of Commodity Programs: Theory and Application to Citrus Canker. *Review of Agricultural Economics* Volume 27, Number 3: 498-504.
- Alston, J. M., Norton, G. W., Pardey, P. G.** 1998. *Science under Scarcity. Principles and Practice for Agricultural Research Evaluation and Priority Setting.* Oxford, UK.
- Aquino, A. P., Bandoles, G.G. & Lim, V.A.A.** 2013. R&D and policy directions for effective control of Fusarium Wilt Disease of Cavendish banana in the Asia-Pacific region, retrieved 15 May 2017.
- Chen, X., Dong, T., Huang, Y. & Yi, G.** 2013. Socio-economic impact of Fusarium wilt on Cavendish banana in China. Paper presented at the Consultation-Workshop on the Socio-economic Impacts of Fusarium Wilt Disease of Cavendish Banana in the Asia-Pacific Region. Davao City, Philippines, 11-15 November.
- Cook, D. C., Taylor, A. S., Meldrum, R. A. & Drenth, A.** 2015. Potential economic impact of Panama disease (tropical race 4) on the Australian banana industry. *Journal of Plant Diseases and Protection*, Vol. 122, No. 5/6: 229-237.
- May, S. & Plaza, G.** 1958. *The United Fruit Company in Latin America.* National Planning Association.
- Ordonez N, Seidl MF, Waalwijk C, Drenth A, Kilian A, Thomma BPHJ, et al.** 2015. Worse Comes to Worst: Bananas and Panama Disease—When Plant and Pathogen Clones Meet. *PLoS Pathog* 11(11).
- Pemsl, D.E. & Staver, C.** 2014. Strategic assessment of banana research priorities. Lima, CGIAR Research Program on Roots, Tubers and Bananas (RTB). RTB Working Paper 2014-2.
- Peterson, E. & Orden, D.** 2006. Linking Risk and Economic Assessments in the Analysis of Plant Pest Regulations: The Case of U.S. Imports of Mexican Avocados. Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Long Beach, California, July 23-26.
- Ploetz, R. C. & Pegg, K.** 1997. Fusarium wilt of banana and Wallace's line: Was the disease originally restricted to his Indo-Malayan region?. *Australasian Plant Pathology* 26: 239-249.
- Ploetz, R. C.** 2015. Fusarium wilt of banana. *Phytopathology* 102: 1512-1521.
- Ploetz, R. C.** 2015. Management of Fusarium wilt of banana: A review with special reference to tropical race 4, *Crop Protection* 73, 7-15.
- Scheerer, L., Pemsl, D., Dita, M., Perez Vicente L. & Staver, C.** 2018. A quantified approach to projecting losses caused by Fusarium Wilt Tropical Race 4. *Acta horticulturae*, 1196, March 2018.
- Scheerer, L., Staver, C., Dita, M., Perez V., L. & Pemsl, D.** 2018. Strategic assessment of Banana Fusarium Wilt research priorities. A quantified approach to project losses caused by Fusarium Wilt Tropical Race 4 & results of the ex-ante assessment of four Fusarium research options. CGIAR Research Programme on Roots, Tubers and Bananas (RTB). Lima, RTB Working Paper.
- Stokstad, E.** 2019. Devastating banana disease may have reached Latin America, could drive up global prices. *Sciencemag.org*, 17 July 2019. (also available at [www.sciencemag.org/news/2019/07/devastating-banana-disease-may-have-reached-latin-america-could-drive-global-prices](http://www.sciencemag.org/news/2019/07/devastating-banana-disease-may-have-reached-latin-america-could-drive-global-prices)).

