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Underestimation of the economic impact of moniliasis and witches' broom on *Theobroma cacao* L.

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This perspective article analyzes the underestimation of the economic impact of moniliasis (*Moniliophthora roreri*) and witches' broom (*Moniliophthora perniciosa*) on Ecuadorian cocoa. The authors argue that these diseases are structural socioeconomic threats that compromise the competitiveness of the largest exporter of fine aroma cocoa. The study distinguishes between the biological effects of both pathogens: moniliasis causes immediate losses in pods (up to 80%), while witches' broom affects the vegetative structure, reducing productivity in the medium and long term. This situation has normalized low yields, even in clones such as CCN-51, showing that varietal resistance alone is insufficient. Data from 44 producers in Guayas and Los Ríos illustrate that losses in 2023 represented 35.9% of production. On average, each producer lost \$1,042.14, leaving a net annual income of \$1,859.21, which is below the minimum living wage in Ecuador. The manuscript concludes that it is imperative to move toward a comprehensive solution that combines good agricultural practices, epidemiological intelligence systems, and cooperative governance models with access to credit. It is recognized as a limitation that the results are a contextual approximation based on a small sample and not a definitive national estimate.

KEYWORDS

agriculture, cacao (*Theobroma cacao* L.), desarrollo científico y tecnológico, impacto económico, sustainability

Introduction

The underestimation of the economic impact of diseases affecting cocoa in Ecuador is a structural problem that remains invisible in both official statistics and public policy-making processes. This situation is particularly worrying given that the country is the world leader in the fine aroma cocoa market, a position that is threatened by the persistence of moniliasis (*Moniliophthora roreri*) and witches' broom (*Moniliophthora perniciosa*), endemic diseases whose sustained presence over time has been widely documented as causing severe and recurrent production losses that compromise the stability of the cocoa system and progressively erode its international competitiveness (Córdova, 2025; Reina et al., 2023; Abad et al., 2018; Pino et al., 2023; Colombatti-Moran and Ruiz Parrales, 2024).

Although moniliasis (*Moniliophthora roreri*) and witches' broom (*Moniliophthora perniciosa*) are often analyzed together due to their cumulative impact on cocoa productivity, both diseases have substantive differences in their biology, epidemiology, and

economic consequences. Moniliasis mainly affects pods and causes direct and immediate losses within the same production cycle, while witches' broom compromises shoots, flowers, and vegetative structures, reducing the plant's productive capacity in the medium and long term. From an economic perspective, this distinction means that the former is associated with visible, short-term production shocks, while the latter generates cumulative and persistent losses whose effects are often less evident in annual statistics but more profound for the sustainability of the production system (Reina et al., 2023; Abad et al., 2018).

This persistent phytosanitary condition has contributed to normalizing structurally low yield levels even in technified systems and in widely disseminated clones such as CCN-51, whose moderate susceptibility limits its ability to compensate for losses caused by epidemiological pressure, a situation that favors the systematic underestimation of the economic and social impacts of these diseases and that translates into a direct impact on the economic stability of thousands of rural families and on the competitiveness of the cocoa sector at the national level (Añazco et al., 2024; Abad et al., 2018; Barberán-Macías, 2017).

From a phytopathological perspective, the persistent dynamics of moniliasis and witches' broom (*Moniliophthora perniciosa*) hinder its eradication and transform its effects into structural problems in the cocoa production system, given that *Moniliophthora roreri* repeatedly compromises fruit production while *Moniliophthora perniciosa* deteriorates the vegetative architecture and productive capacity of plants over several consecutive cycles. This difference in their mode of action explains the magnitude and continuity of the losses observed and highlights the inadequacy of strategies based exclusively on the adoption of productive clones such as CCN-51 to neutralize a complex and persistent epidemiological pressure (Abad et al., 2018; Añazco et al., 2024).

There are also significant gaps in our comprehensive understanding of the economic problem associated with these diseases, as there is no consensus on their true magnitude and public policies have failed to coherently articulate the phytosanitary, social, and commercial dimensions of cocoa. This contributes to the institutional normalization of losses as an inevitable cost of production and reduces the pressure to design comprehensive economic frameworks capable of highlighting the real cost of the disease to the country, limiting the adoption of early warning systems, sustained technical extension programs, and financing schemes aimed at risk management (Pino et al., 2023).

This perspective article argues that moniliasis and witch's broom (*Moniliophthora perniciosa*) should be analyzed not only as agronomic challenges, but also as significant socioeconomic threats. We propose that the economic impact be reassessed from a comprehensive approach that articulates productivity, rural sustainability, and international competitiveness.

The structure of this perspective article is as follows: first, the epidemiological and economic aspects of both diseases are described; next, case studies showing specific losses in different provinces are presented; and finally, a critical reflection is offered on the need to reassess their economic impact as an indispensable step toward a sustainable cocoa policy.

The biological problem and economic impact of *Theobroma cacao* L.

To begin with, the underestimation of the economic impact of moniliasis and witches' broom (*Moniliophthora perniciosa*) is due to the biological complexity of both pathogens. First, *Moniliophthora roreri* directly affects cocoa pods, causing losses that can reach up to 80% of production (Abad et al., 2018; Lapo et al., 2023), while *Moniliophthora perniciosa* compromises buds and buds, reducing the productive capacity of plants for several consecutive cycles (Sousa Filho et al., 2021) as shown in Figure 1.

This phytopathological dynamic is exacerbated by its endemic nature and the difficulty of eradication. As a result, these diseases are becoming structural rather than circumstantial problems (Alvarado et al., 2017). In other words, these pathogens are difficult to detect early on, and their constant presence in cacao trees has normalized low yields, contributing to an underestimation of their impact.

In addition, commercial clones such as CCN-51, widely used for their productivity, show moderate susceptibility (Abad et al., 2018), refuting the belief that varietal replacement is sufficient to solve the problem. For example, in one of the provinces, the presence of 100% moniliasis and its coexistence with witch's broom (*Moniliophthora perniciosa*) and black ear was confirmed, demonstrating that the problem persists even in *technified* systems (Abad et al., 2018). As a result, cultural and biological control, although necessary, is insufficient to eliminate epidemiological pressure (Ferraz et al., 2019).

In this regard, emerging threats such as Ceratocystis wilt (Lloren, 2023) or the cocoa swollen shoot virus (Adesah et al., 2023) could aggravate the phytosanitary situation. Consequently, the lack of active surveillance and standardized diagnostic protocols contributes to silencing the biological problem, skewing economic analyses.

The economic data presented in Table 1 does not come from a primary survey conducted within the framework of this article, but rather derives from a previous study based on structured surveys of forty-four cocoa producers belonging to the Union of Cocoa Organizations (UNOCACE), located in producing areas in the provinces of Guayas and Los Ríos. This information is incorporated into this manuscript as a secondary source for the purpose of empirically contextualizing the magnitude of the economic losses faced by small organized producers affected by moniliasis and witches' broom (*Moniliophthora perniciosa*), allowing us to illustrate the economic impact observed in a specific segment of the cocoa system without attempting to establish representative estimates at the national level.

In this context, and from an economic perspective, cocoa is one of the pillars of Ecuadorian agricultural exports; however, Table 1 shows the losses suffered by small farmers due to disease. In particular, data from the Union of Cocoa Organizations (UNOCACE) reveal that in 2023, combined losses from moniliasis and witches' broom (*Moniliophthora perniciosa*) exceeded \$45,000, affecting 35.9% (Pino et al., 2023). It should be noted that these figures imply that each producer lost an average of \$1,042.14, with an annual net income of only \$1,859.21, which is less than the annual minimum wage in Ecuador (Pino et al., 2023).

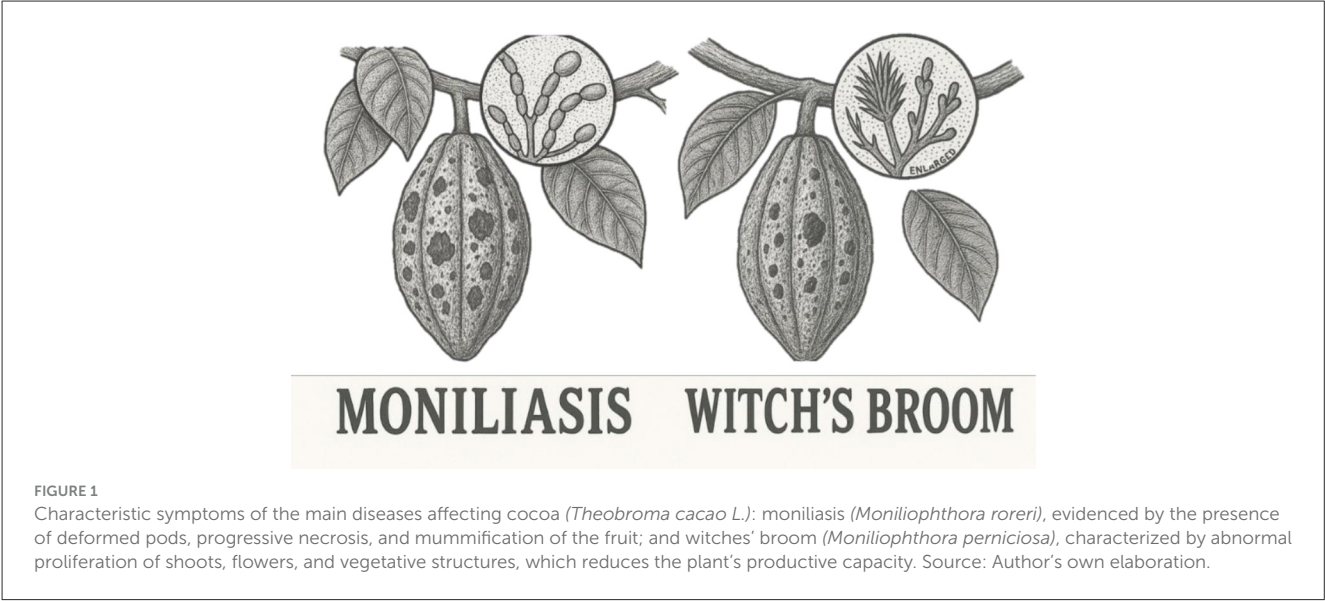


FIGURE 1
Characteristic symptoms of the main diseases affecting cocoa (*Theobroma cacao* L.): moniliasis (*Moniliophthora roreri*), evidenced by the presence of deformed pods, progressive necrosis, and mummification of the fruit; and witches' broom (*Moniliophthora perniciosa*), characterized by abnormal proliferation of shoots, flowers, and vegetative structures, which reduces the plant's productive capacity. Source: Author's own elaboration.

TABLE 1 Economic losses due to moniliasis and witch's broom (Pino et al., 2023).

Concept	Moniliasis (<i>M. roreri</i>)	Witch's broom (<i>M. perniciosa</i>)	Estimated total	Observations
Total recorded loss (USD)	26.374,55	19.479,67	45.854,22	Equivalent to 35.9% of production
Average loss per producer (USD)	599,42	442,72	1.042,14	Calculation based on 44 producers from an estimate of 240,000 cocoa growing families.
Annual net income per producer (USD)	1.859,21	-	1.859,21	Below the minimum annual living wage
Average yield achieved (kg/ha)	316	316	316	Well below the potential of CCN-51 (4000 kg/ha)

Prepared by the authors based on data from Pino et al. (2023).
The data correspond to secondary information obtained from a previous study based on surveys conducted among 44 cocoa producers affiliated with UNOCACE, located in the provinces of Guayas and Los Ríos. The sample represents small producers organized under similar production conditions. The results are indicative and do not constitute representative estimates at the national level.

The results in Table 1 show that current losses have a double negative effect: they reduce production and harm family wellbeing. Estimates indicate that, if no action is taken, cumulative losses over the next 5 years would exceed \$229,000. However, if comprehensive management is implemented to reduce the impact to 10%, each producer's income could double, exceeding the basic income for each year.

Challenges and opportunities of underestimating diseases in a comprehensive solution proposal

First, research conducted in the Ecuadorian cocoa sector has documented that the adoption of good agricultural practices can drastically reduce the incidence of monilia, as occurred in one of the provinces, where it was reduced from 40 to 5% on farms that applied sanitary pruning and adequate fertilization (Rodríguez et al., 2020; Añazco et al., 2024; Rodrigues et al., 2025). Although this study showed an immediate positive impact, Pino et al. (2023) found the opposite in another province, where more than 40%

of farmers did not apply phytosanitary controls, keeping loss levels high. We believe that this divergence reflects an excessive dependence on social and organizational factors, rather than on the technical validity of the practices, which explains why their effectiveness is heterogeneous.

Secondly, international literature suggests that the lack of comprehensive public policies exacerbates the underestimation of the problem. For example, Córdova (2025) emphasized the quality and “country brand” of fine-flavor cocoa, but omitted recurring phytosanitary costs, while Oladokun et al. (2025) in Nigeria quantified losses due to *Phytophthora* using replicable methodologies that could be adapted to the Ecuadorian cocoa sector. However, the sample used by Pino et al. (2023) was limited to a single farmer organization, which restricts the generalization of the results and, in turn, reflects institutional weakness: national statistics prioritize production and exports but do not systematically measure “loss of profits due to pathogens.”

We believe that this combination of practical limitations and institutional shortcomings leads to the economic problem being overlooked. In other words, chronic losses are normalized as if they were inevitable, reducing political pressure to invest in early

warning systems or extension programs. This could be resolved by incorporating official phytosanitary loss indicators into provincial dashboards, using methodologies similar to those applied in other countries (Oladokun et al., 2025).

Thirdly, the proposed comprehensive solution must go beyond the agronomic sphere. It is a priority to strengthen agroforestry based on climate information, given that (Arakeri et al., 2024) demonstrated that diversified systems do not increase the incidence of disease and improve resilience. Applied bioeconomy should also be promoted, in which the development of biological control agents and validated cultural practices, such as those described by Ferraz et al. (2019), are integrated into mass extension programs. At the same time, it is advisable to implement epidemiological intelligence systems, such as the predictive models used in one province that made it possible to anticipate outbreaks of moniliasis (Chávez Cruz et al., 2018).

Finally, from a public policy perspective, we argue that it is necessary to establish lines of credit for health and a cooperative governance model, with the participation of the state, peasant associations, and the private sector, as proposed by Zambrano et al. (2024). In conclusion, the only way to overcome underestimation is to combine technical solutions with solid institutional frameworks and inclusive financial mechanisms, so that losses are no longer considered an inevitable cost and become a manageable challenge to ensure the sustainability of Ecuadorian cocoa.

Although the study provides a detailed analysis of the economic impact of moniliasis and witches' broom (*Moniliophthora perniciosa*) on cocoa production, it is necessary to explicitly acknowledge certain limitations inherent in its design and scope, given that the empirical evidence used comes from a previous study based on a small sample of 44 producers located in the provinces of Guayas and Los Ríos, a condition that limits the possibility of extrapolating the results to the national level. Added to this is the reliance on secondary information and the indicative nature of the data used, these aspects must be carefully considered when interpreting the findings, which is why conclusions regarding the economic impact at the country level should be understood as contextual approximations or generators of hypotheses rather than definitive statements. It would be desirable for future research to incorporate samples with greater territorial coverage or to develop formal models that integrate economic and phytosanitary assumptions of national scope.

References

- Abad, M. L., Abad-Sánchez, A. A., Alvarado-Aguayo, A. A., and Gallardo-Campoverde, A. (2018). *Análisis Comparativo Sobre la Incidencia de las tres Principales Enfermedades en el Cacao CCN-51, En el Cantón La Troncal, provincia del Cañar*, Ecuador: Revista Científica Ciencias Naturales y Ambientales.
- Adesah, T., Osei, C., Tham-Agyekum, E. K., and Bakang, J.-E. A. (2023). Improving support systems for cocoa farmers beyond cocoa swollen shoot virus disease infestation. *J. Soc. Econ. Agricult.* 12:10. doi: 10.26418/j.sea.v12i1.64388
- Alvarado, A. A., Holguín Burgos, B. P., Mayra Abad Sánchez, M. L. (2017). *Estudio Económico de la Producción de Cacao y Las Principales Enfermedades de la Variedad ccn-51 en el cantón La Troncal*, Ecuador: Guayas
- Añazco, E. J., Correa-Romero, R., Celi-Sabando, K. D., and Purcachi-Ramos, V. E. (2024). Buenas Prácticas Agrícolas (GAPS) en el Cultivo de Cacao (*Teobroma cacao*) Injerto en la Parroquia Luz de América. *Rev. Soc. Front.* 4, 152–165. doi: 10.59814/resofro.2024.4
- Arakeri, M., Dhatvik, M. P., Kavan, A. V., Murthy, K. S., Nishitha, N. L., and Lakshmi, N. (2024). Intelligent pesticide recommendation system for cocoa plant using computer vision and deep learning techniques. *Environ. Res. Commun.* 6:075003. doi: 10.1088/2515-7620/ad58ae
- Barberán-Macías, F. J. (2017). *Determinación del control fitosanitario de monilla (Monilia sp.) en Cacao Nacional con dos productos comerciales, en el cantón Balzar en la provincia del Guayas*, Guayaquil.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

LM: Writing – review & editing, Writing – original draft, Investigation. JM: Conceptualization, Writing – review & editing.

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- Chávez Cruz, G., Olaya Cum, R., and Maza Iñiguez, J. (2018). Costo de producción de cacao clonal ccn-51 en la Parroquia Bellamaria, Ecuador. *Univ. y Sociedad*, 10, 179–185. http://scielo.sld.cu/scielo.php?pid=S2218-36202018000400179&script=sci_arttext (Accessed November 1, 2025).
- Colombatti-Moran, P. S., Ruiz Parrales, Y. G. (2024). *Evaluación y Caracterización de la Sustentabilidad en Fincas Productoras de Cacao (theobroma cacao L.) del Cantón Baba*, provincia de Los Rios. *Conocim. Glob.* 9, 152–165. doi: 10.70165/cglobal.v9iS1.482
- Córdova, E. G. (2025). Cacao fino de aroma: comercio interno en el Ecuador. *Arandu UTIC* 11, 3365–3380. doi: 10.69639/arandu.v11i2.506
- Ferraz, P., Cássio, F., and Lucas, C. (2019). Potential of yeasts as biocontrol agents of the phytopathogen causing cacao witches' broom disease: is microbial warfare a solution? *Front. Microbiol.* 10:1766. doi: 10.3389/fmicb.2019.01766
- Lapo, D. J. C., Cambo, M. N. R., Sailema, W. G. C., and Encarnación, P. S. A. (2023). Desarrollo de un modelo predictivo utilizando técnicas de aprendizaje supervisado para detectar la moniliasis en plantas de cacao de la Provincia de Orellana. *Rev. Tecnol. - ESPOL*. 35, 46–67. doi: 10.37815/rte.v35n3.1069
- Lloren, R. (2023). Unveiling Ceratocystis wilt disease: a review of cocoa's unforgiving foe. *IOP Conf. Series Earth Environ. Sci.* 1263:012008. doi: 10.1088/1755-1315/1263/1/012008
- Oladokun, Y., Agbeniyi, S., Agulanna, F., and Oluyole, K. (2025). Assessing the economic burden of black pod disease and cherelle wilt on cocoa farmers in Nigeria. *Afr. J. Agricult. Sci. Food Res.* 18, 112–119. doi: 10.62154/ajasfr.2025.018.010621
- Pino, C. W., Herrera, H., and Garabiza Castro, B. D. R. (2023). *Estimación de pérdidas económicas en Cacao causado por Escoba de Bruja (Crimipellis Perniciosa) y Monilia (Monilia Roreri) en pequeños productores.* *Rev. de la Univ. del Zulia*. 15, 179–192. doi: 10.46925/rdluz.42.15.2024.179
- Reina, A. M. M., Zumaqué, L. T., Martinez, L. M. G., Pinto, M. V. R., Cabadiáz, A. D., and Leal, H. A. B. (2023). Determinantes para el manejo de enfermedades en cacao (*Theobroma cacao* L.) en el sur de Córdoba, Colombia. *Ciencia y Agricult.* 17, 1–8. doi: 10.18779/cyt.v17i2.712
- Rodrigues, G. V. P., Santos, J. P. N., Ferreira, L. Y. M., Conceição, L. B. D. A., Porto, J. A. M., and Aguiar, E. R. G. R. (2025). *Theobroma cacao* Virome: exploring public RNA-Seq data for viral discovery and surveillance. *Viruses* 17:624. doi: 10.3390/v17050624
- Rodríguez, D. H., Martínez-Botello, H., and Posada. (2020). *Enfermedades del cultivo del Cacao*. doi: 10.21930/agrosavia.video.2020.10
- Sousa Filho, H. R., De Jesus, R. M., Bezerra, M. A., Santana, G. M., and De Santana, R. O. (2021). History, dissemination, and field control strategies of cocoa witches' broom. *Plant Pathol.* 70, 1971–1978. doi: 10.1111/ppa.13457
- Zambrano, G., Tennhardt, L. M., Egger, M., Ramírez, K., Santos, A., Moyano, B., et al. (2024). Differing impacts of the COVID-19 pandemic on farmers and intermediaries: insights into the Ecuadorian cocoa value chain. *Agricult. Food Econ.* 12:9. doi: 10.1186/s40100-024-00302-0