Understanding cacao pod hazard avoidance and yield losses through survival analysis and microclimate

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INTRODUCTION

The epidemiological study of tropical diseases in perennial crops such as cocoa is a complex task, especially for a long-cycle disease such as Frosty pod rot (FPR), caused by the fungus Moniliophthora roreri (Cif.)**4.** FPR is considered the biggest hazard of cacao cultivation in Latin America affecting crop yield considerably**3.** In addition, there is a constant threat of the arrival of FPR in countries such as the Dominican Republic and the main producing countries in West Africa, which will lead to major crop losses thus disrupting the world cocoa industry**1.** To develop efficient management options to control FPR, a better understanding of the influence of microclimate on the epidemiology of FPR and its effect on crop yield is needed**2.** In this study, a data set of **+9000 cacao pods** from three clones was tagged and observed fortnightly for 55 weeks in humid lowland Costa Rica. Weather records for the same period were also retrieved to explore the dynamic of FPR epidemiology and pod infection risk. To do so, a three-step analysis was followed: 1) **Kaplan-Meier approach** was applied to analyze the potential non-climate factors on the FPR hazard, 2) modeling of the **survival behavior** of cacao pods using covariates linked to clones, bagging and pod's trunk position and 3) the **Cox model approach** using time-dependent covariables to test the significance of microclimate variables on FRP dynamic and pod hazard avoidance.

LITERATURE CITED

1. Krauss, U., et al. (2006). Early detection of frosty pod rot as key to cost-effective control.
2. Leandro-Munoz, M. E. et al.. Effects of microclimatic variables... PLoS One, 12(10).
3. Phillips-Mora, W. (2003). Origin, biogeography, genetic diversity and taxonomic affinities...
4. Zadoks, J. C., & Schein, R. D. (1979). Epidemiology and plant disease management...

METHODS

Hazard function

$h(t)$: hazard function at time t associated to:

h_0: baseline hazard function

Response variable

Time of each pod until:

appearance of FPR symptoms

Model for the *i*-th pod

$$\log\left[\frac{h_i(t)}{h_0(t)}\right] = \beta_0 + \sum_{l=1}^{4}\beta_l X_{li} + \beta_5 X_{1i}X_{3i} + \beta_6 X_{2i}X_{3i} + b_1 Z_i(t) + b_2 Z_i^2(t)$$

Covariates

Fixed

- X_1 : indicator of CC137 clone
- X_2 : indicator of Pound7 clone
- X_3 : indicator of no-bagging usage
- X_4 : indicator of location above 1.5m

Time-dependent

$Z(t)$: wetness frequency

RESULTS

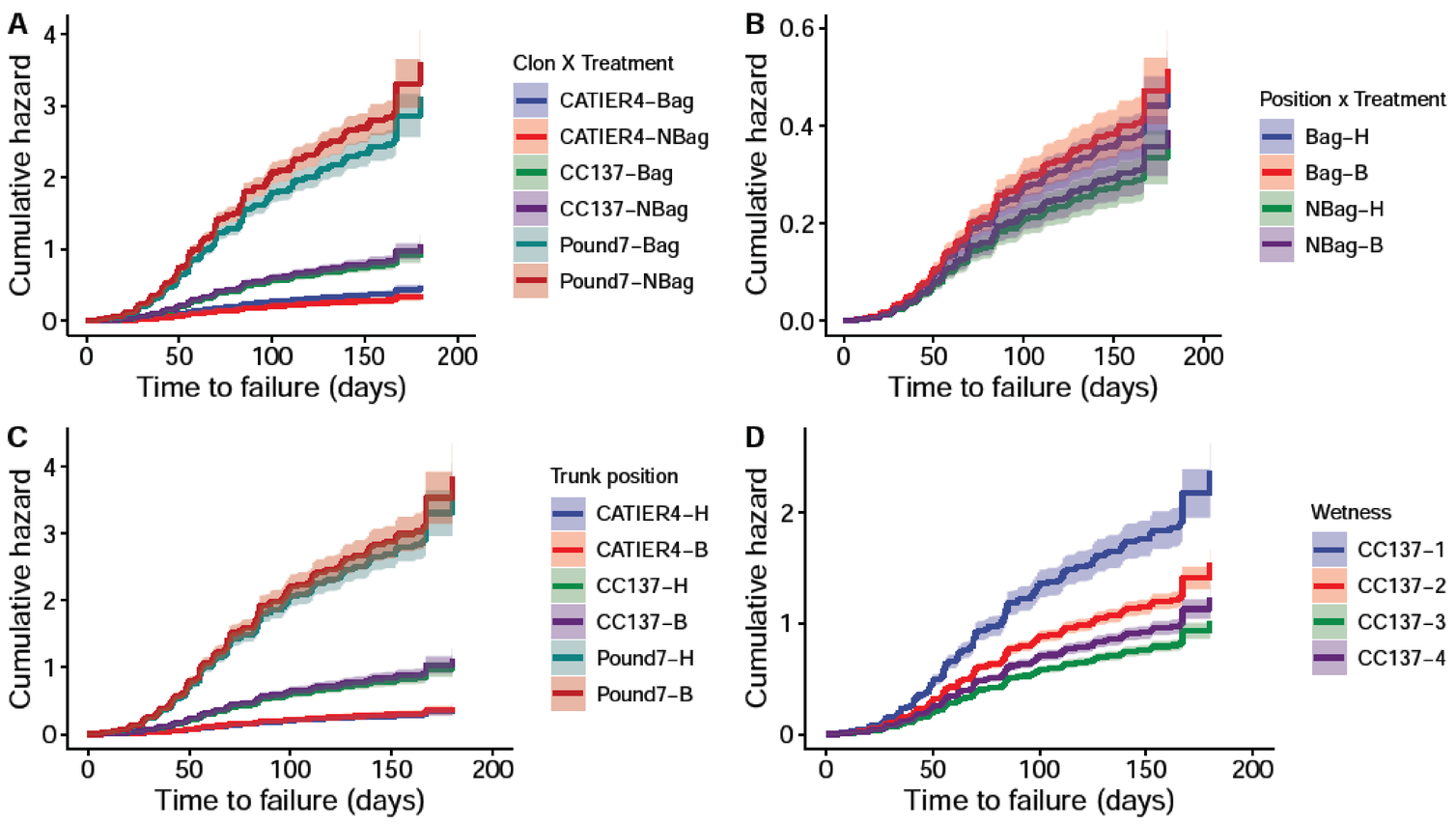

Figure 1. Comparison of expected cumulative hazard functions with their respective 80%-confidence intervals.

STUDIED VARIABLES

Table 1. Categorical variables for infected and harvested

		Harvest		Monilia	
Clon	CATIER4	1078	67.67%	515	32.33%
	CC137	934	37.27%	1572	62.73%
	Pound7	158	5.29%	2827	94.71%
Treatment	Bagging	1187	31.64%	2565	68.36%
	No bagging	983	29.50%	2349	70.50%
Location	below 1.5m	369	21.78%	1325	78.22%
	above 1.5m	1801	33.41%	3589	66.59%

Table 2. Fitted relative risks for model

Comparison	Fixed Level	Estimate	95%-Confidence Interval
Location above vs below	None	0.9361	(0.8780, 0.9980)
No Bagging vs Bagging	Clone CATIER4	0.7601	(0.6355, 0.9091)
	Clone CC173	1.0649	(0.9638, 1.1767)
	Clone Pound7	1.1562	(1.0739, 1.2448)
Clone CC173 vs CATIER4	No bagging	2.2020	(1.9294, 2.5132)
	Bagging	2.0677	(1.8204, 2.3487)
Clone Pound7 vs CATIER4	No bagging	7.4983	(6.6312, 8.4787)
	Bagging	6.4853	(5.7321, 7.3376)

DISCUSSION

- Pods located lower (≤1.5 m) in the trunk face a risk of 6% higher than pods located above (Table 2).
- There is a significant interaction between bagging X clone, i.e. if we compare the no-bagging against bagging usage, the effect is different among clones: (1) 24% reduction in FPR risk for CATIER4, (2) non-significant change in CC137 clone and (3) 16% increase in FPR risk in Pound7 (Table 2).
- The infection risk of clone CC137 with respect to CATIER4 is more than twice when we consider the bagging effect fixed. There are no significant differences in the comparison among bagging levels.
- The infection risk of clone Pound7 with respect to CATIER4 is 7.5 times greater when the pods are not bagged and 6.48 times when it is covered (Table 2).

- There are significant differences in terms of cumulative risk of pod infection among clones but not due to bagging within the clones (Figure 1A).
- No significant differences regarding the accumulated risk of infection for the combination of bagging and pod position along the trunk was found (Figure 1B).
- Pod bagging shown no significant differences in the cumulative risk infection among sampled clones. For most clones, pods located above 1.5 m seem to be key to avoiding the risk of infection (Figure 1C).
- For clon CATIER-4 with no bagging and "above" location, as pod wetness increases the risk of the disease increases, however, when the value is above 83% the opposite occurs (Figure 1D).

CONCLUSIONS/RECOMENDATIONS

- Genetic resistance, as tested here, constitutes one of the best alternatives to avoid FPR infection.
- Keeping pod load in the upper portion of the trunks could aid FPR hazard avoidance.
- Regulating shade levels for a better air flow within the plot is key to reduce pod wetness, and therefore the risk of FPR infection.