International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 8 Issue 6, Nov-Dec 2024 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Comparative Effect of Three Approaches of Fungicide Control of Cocoa Black-Pod-Rot Disease on Mountainous Humid Cocoa Farm in Kekem, Cameroon

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ABSTRACT

Background:
Cocoa is an industrial crop, playing a major role in the micro and macro-economy of many Africa countries, with recommendable contribution to the livelihood of the populations. The Cameroonian government recognizes the importance of the cocoa sector for its economy and announced ambitious goals to expand cocoa production. Unfortunately, black pod rot, caused by *Phytophthora megakarya*, has long been the nightmare of cocoa farmers.

Aim:
The study aimed at comparing the effect of three approaches of fungicide control of cocoa black-pod-rot disease on mountainous humid cocoa farm in Kékem, Cameroon.

Methodology:
The experimental design consisted of three phases (approaches) of treatment applied to three different fungicides distributed at random to three farm blocks. In this Restricted Randomized Block Design, phase I consisted of treating every two weeks, phase II every 10 days and phase III every two weeks with two targeted treatments in between two treatments. Phytosanitary removal of rotten pods was systematically applied to all the blocks. The normality assumption was violated for all the variables (Kolmogorov Smirnov and Shapiro-Wilk test: $P<0.05$), thus, the non-parametric Kruskall Wallis test was used to compare groups for significant difference.

Results:
In overall, there was a drop in cocoa black-pod-rot across the phases with phase III being the most efficient, with an average percentage loss due to black pod rot of 17.5%. This was followed by phase II with a percentage loss of 24.5%, while phase I was the least efficient in controlling black pod rot with a percentage loss of 31.4%, and this difference was statistically significant (KWT: $P=0.001$). Comparing within treatment, the trend was the same, with Phase III approach the most efficient and Phase I the least.

Conclusion:
Phase III approach proved to be more efficient and moreover consuming the lesser amount of fungicide as compared to the second phase. Though the consumption of fungicide was the least in the first phase, the losses were 13.9% higher as compared to Phase III, which is a conservative-proportionate increase of 79.4%. This gain in fungicide was too far from economically compensating the losses, thus making Phase III approach the most cost-effective, as it even consumed lesser fungicide as compared to Phase II.

Recommendations:
It was recommended that spacing fungicide application in the control of cocoas black-rot-pod, coupled with targeted treatments for critically affected spots, reduce not only the intensity of rotten pods, but equally consumed lesser fungicide with major advantages for the environment while been economically cost-effective. Phytosanitory removal of rotten pods was generally applied in prospect of integrated disease control, which is an added value for sustainable farming system.

How to cite this paper: Nana Celestin | Stephanie Signe Mamba "Comparative Effect of Three Approaches of Fungicide Control of Cocoa Black-Pod-Rot Disease on Mountainous Humid Cocoa Farm in Kekem, Cameroon" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-8 | Issue-6, December 2024, pp.172-180, URL: www.ijtsrd.com/papers/ijtsrd70518.pdf

IJTSRD70518

***KEYWORDS:** Fungicide, control, cocoa, black-pod-rot, humid mountainous farm, Kékem, Cameroon*

INTRODUCTION

Cocoa is an industrial crop, playing a major role in the micro and macro-economy of many Africa countries, with major contribution to the livelihood of the populations. As ascertain by Wainaina & Minang (2024), this contribution is not only through income, but employment as well. In Cameroon, direct employment by cocoa was estimated to 400,000 households (Minader, 2018). Global demand for cocoa has been growing steadily and sharply over the years. By 2020-2025, one million additional tons of cocoa will be required to meet the world demand (Wainaina & Minang, 2024). Cameroon is currently the fourth largest cocoa producer in the world, with a production level between 280,000 and 290,000 Metric Tons (MT) per year in the last two years (Elorm, 2022). The cocoa sector is an important source of job creation, with an estimate of around 400,000 jobs generated by the cocoa value chain: 293,000 farmers, 2,800 formal workers, 73,000 rural workers at full-time equivalent, and 29,200 family jobs. Moreover, cocoa is an important source of State revenue (Elorm, 2022). The cocoa value chain in Cameroon generates a total (direct + indirect) value added of €400 million and contributes 1.2% to the national GDP and 8.2% to the agricultural GDP. When considering the €7,8 million invested in public subsidies and several projects, the cocoa value chain generates a balance of around €37 million per year contributing to the public finances of the country (Elorm, 2022). The Cameroonian government recognizes the importance of the cocoa sector for its economy and announced ambitious goals to expand cocoa production to 600,000 MT by 2025 and doubling this quantity by 2030 (Elorm, 2022). Cocoa is a major source of income for millions of people worldwide. The top four exporting countries are Cote d'Ivoire, Ghana, Ecuador and Cameroon (FAO, 2024). The sector is of systemic importance, as it represents the second source of export revenues for the country, after oil (Mvogo, 2021). However, the impact on the environment cannot be underestimated; it is in this vein that numerous measures have been taken to enhance sustainable or environmentally-friendly cocoa farming (Ngoma et al., 2018). In this perspective, FAO (2024) emphasized the need of assessing the risk of deforestation and degradation linked to cocoa farming, a risk that is particularly high given the current trend in cocoa prices.

Background

Most of the cocoa plantations that are still in production today in Cameroon were created during 1920's and 1930's (Dounias, 2000). Cocoa is believed to have been introduced in Cameroon between 1886/1887 during the era of German governor Julius Von Soden (Klarer, 2014; National Cocoa and Coffee Board, 2024). These German settlers established large plantations, both in size and in the resources mobilized for their creation and upkeep. This was particularly true of the Victoria Molyko Estate, worth over 1042 million Francs CFA in 1972, stretching 12695 hectares with 100 residential buildings and a 42 km railway line. Workers of these plantations came from Bali, Foumban, Kribi, Lolodorf, Ebolowa and Yaounde. In 1903, in order to compel farmers to work on these plantations, the Germans instituted the Head tax. Those unable to pay in cash were given the option to work for 30 days annually on these plantations (National Cocoa and Coffee Board, 2024). By 1912, there were 13161 hectares of cultivated land with total exports reaching 4551 tons (National Cocoa and Coffee Board, 2024). In colonial Cameroon between 1914 and 1960, cocoa was a crop mainly produced on African smallholdings (Eckert, 1996) and played a crucial role in the economy of the French territory at that time, especially after World War II. Over 500,000 Cameroonians in the French sphere, that is approximately 12 percent of the entire population, were more or less dependent on cocoa during the last decade of colonial rule (Eckert, 1996). Nearly 50 percent of all export earnings came from the sale of cocoa, making the entire economy precariously dependent on the world market price of this crop. The Cameroonian share of the cocoa world production was around 6 percent at the end of the colonial period (Joseph, 1977; Jakobeit, 1991). Cocoa production in the cocoa belt of south central Cameroon, by far the most important cocoa region, in the 1940s and 1950s, was based almost exclusively on small-scale family plots (Joseph, 1977; Inspection Generale de 1'Agriculture, 1954). Until 1940, however, some Cameroonians grew cocoa on a scale and in a nexus of social relations which were far removed from the traditional picture of the smallholder cultivating communal land with family labor (Eckert, 1996). Cocoa production after the independence around the years 1960s have grown steadily till date with Southwest Development Authority (SOWEDA) being enhancing its production in the Southwest region of Cameroon. Cameroon produced approximately 225 thousand tons of cocoa beans in 2012/2013 and is expected to produce 300 thousand tons in 2023/2024. This high increase in production cannot without stresses on the environment, thus promoting for several initiatives toward sustainable or environmental-friendly cocoa production over the past three decades (Ngoma et al., 2018; FAO, 2024). The production of cocoa has been impede not only by the drastic dropped in prices over the years before the sharp rise observed last year which seem to be sustained over the 2024/2025 campaign, but also by pests and diseases as well as the aging of farmers' population due to rural exodus. It is expected that recent boost in cocoa prices will encourage youth to return to rural areas to benefit from this promising economic activity. Black pod rot, caused by *Phytophthora megakarya*, has long been the nightmare of cocoa farmers. It is the main cause of cocoa harvest losses in Cameroon and many other African countries (Ndoumbe-Nkeng et al., 2003). Beans from pods attacked by the disease are not suitable for processing and must be discarded; moreover, the disease will not even allow the affected pods to grow to maturity. Losses can reach 100% of annual production if no control measures are taken. Cacao black pod is a particularly economically serious problem in all cacao-producing regions of the world (Guest, 2007; Adomako, 2004; Dormon et al., 2004; Anon, 2004; Gregory, 1981; Matos et al., 1998). Annual yield losses due to black pod may range from 20% to 30%, although individual farms may suffer from 30% to 90% (Hebbar, 2007), being especially severe in West and Central Africa, causing up to 64% of losses in plantations (Adomako, 2007; Dormon et al., 2004), although it is reported to also be one of the main causes of pod losses in Southeast Asia (Anon, 2004). The disease is caused worldwide by various species of *Phytophthora*, with the species *Phytophthora megakarya* Brasier and Griffin predominating in Cameroon (Nyasse, 1992), but strains of *P. palmivora* Butler seem to be present too (Ducamp, 2003). The methods available for controlling cocoa black pod rot are fungicide application, use of resistant cultivars and other appropriate cultural practices. But Berry & Cilas (1994) are of the opinion that combining these methods will lead to an increase in the effectiveness of control. Among the aforementioned methods, appropriate cultural practices seem to be the simplest to apply, in both terms of costs and environmental conservation. These practices should create conditions unfavorable for pathogen development and inoculum production. In this vein, we can highlight Phytosanitary pod removal, which is a preventive method and consists in cleaning trees at the beginning of the season by removing mummified fruits left from the previous season, which are a potential source of primary inoculum, and then regularly removing diseased pods, which are a potential source of secondary inoculum (Muller, 1974; Ndoumbe-Nkeng, 2003). Tondje et al. (1993) tested several combinations of cultural practices in a regularly weeded experimental plot containing a single hybrid. The best disease control was achieved with pruning and removal of mummified pods at the beginning of the season, followed by weekly phytosanitary removals. In Peru, Soberanis et al. (1999) conducted a study on farmers' fields, the purpose of which was to make recommendations for disease control, based on the frequency of phytosanitary removal (at weekly or fortnightly intervals). The authors showed that weekly phytosanitary removal relatively reduced cocoa black pod rot incidence by between 35% and 66%. In this very perspective of integrated management, Merga (2022) resolved that disease losses can be abridged through combined management practices that comprises pruning and shade management, leaf covering, regular and complete picking, hygiene and pod case removal, suitable fertilizer application and targeted fungicide usage. However, fungicide treatment has been broadly used to control cocoa black pod rot. Oduro et al. (2020) is equally among the authors that following experimentation calls for combination of various control measures (including fungicide spraying) to eradicate the disease or at least greatly reduce the prevalence to a tolerable level. Vanegtern et al. (2015) ascertain that although chemical control is an option, it may not be cost effective, depending on the size of the operation and environmental conditions. Acebo-Guerrero et al. (2012) equally emphasized that losses in yield due to black pod could be reduced through integrated management practices, although the results may vary for each cacao-growing region. They then resolved that black pod control could be achieved if an integrated management strategy is established, with the combination of biological and chemical methods, genetic control, and adequate phytosanitary removal.

Objective of the study

The study aimed at comparing the effects of three approaches of fungicide control of cocoa black-pod-rot disease on mountainous humid cocoa farm in Kekem, Cameroon.

Area of study

Cameroon is Central Africa's leading cocoa producer, Africa's fourth largest, and the world's sixth-largest producer. Cocoa (*Theobroma cacao* L.) remains a cornerstone of Cameroon's export-based economy, making it important to assess the influence of climate change on cocoa performance in the country. Over the past 20 years, national production and the surface area planted with cocoa have increased (FAO, 2022). Cameroon is a lower-middle-income country with a population of over 29.4 million in 2024. (United Nations Population Fund, 2024). Located along the Atlantic Ocean., it shares its borders with the Central

African Republic, Chad, Equatorial Guinea, Gabon, and Nigeria. Two of its border regions with Nigeria (Northwest and Southwest) are Anglophone, while the rest of the country is Francophone, both entangled in more than 200 different ethnic groups. Cameroon is endowed with rich natural resources, including oil and gas, mineral ores, and high-value species of timber, and agricultural products, such as coffee, cotton, cocoa, maize, and cassava (WB, 2024). Having enjoyed several decades of stability, Cameroon has in recent years been grappling with attacks by Boko Haram in the Far North and a secessionist insurgency in the Anglophone regions. Since September 2017, this situation has displaced more than one million internally and around 470000 refugees have sought shelter in Cameroon. Following the resurgence of the crisis in the Central African Republic since January 2021, over 6,000 Central Africans refugees fled to Cameroon's East region which was already hosting over 60% of Central African refugees. According to UNHCR September 2023 figures, Cameroon is hosting over 460000 refugees, primarily from the Central African Republic with a proportion of 73% and 26% for Nigeria (WB, 2024). Because its poverty reduction rate is lagging behind its population growth rate, the overall number of poor in Cameroon increased by 12 % to 8.1 million between 2007 and 2014, and poverty is concentrated in the country's Northern regions, where 56 % of the poor live (WB, 2024). The economic outlook is expected to remain moderately favorable over the medium term, but risks are tilted to the downside. Cameroon's real GDP growth is projected to reach 4.2%, on average over 2023-25, supported by sustained activity in the secondary and tertiary sectors (WB, 2024). Kékem is a subdivision of Upper Nkam division in the West region of Cameroon. West Cameroon is the coldest region in Cameroon, with an average daily maximum temperature of only 27 degrees (WorldData, 2024). The landscape is made of planes and mountainous areas. Neo Industry, the newly built cocoa processing unit in Kékem, was officially opened on April 26, 2019. With its annual capacity of 32,000 tons, this unit will increase the national production of cocoa butter and powder. Neo Industry is expected to create about 750 indirect jobs. It is in line with the ambitions of public authorities and sector players who are working to increase local processing. The objective was to locally process 50% of production by 2020. While the national cocoa production was around 200,000 tons over the past five seasons, Cameroon only processed about 25% of volumes, exposing the sector to variations on international market (Business Cameroon, 2019).

Experimental design

The study employed a Restricted Randomized Block Design (RBD) whereby three different fungicides making up the tree experimental treatments were distributed at random to Block A, Block B and Block C (table 1) and were subjected to three Phases (approaches) of treatment. For ethical reasons, the names of the pesticides are not disclosed here, given that permission was not obtained from the manufacturers to use them comparatively in an experimental setting. However, this was not quite an issue since the main purpose of the study was to compare three approaches of treatment though the variability of the data was improved by considering three different fungicides as to control for bias. The brands of the fungicides are not disclosed here for ethical reasons, in order not to affect the cogency of whatever service mark. Phase I consisted of treating every two weeks, Phase II every 10 days and Phase III every two weeks with two targeted treatments in between two treatments. Treatment was carried out within a day in all the blocks for the homogeneity of weather conditions using hand-sprayer by two different operators that equally rotated blocks. Systematic phytosanitary removal of cocoa black pods was done prior to a treatment phase. The duration of each phase was 30 days.

Table 1: Experimental layout

Blocks and treatments	Treatment phases		
	Phase I	Phase II	Phase III
Block A / Treatment A	Two treatments at fortnight interval and data collection after 30 days	Three treatments at 10 days interval and data collection after 30 days	Two treatments at fortnight interval with two targeted treatments in between. then data collection after 30 days
Block B / Treatment B	Two treatments at fortnight interval and data collection after 30 days	Three treatments at 10 days interval and data collection after 30 days	Two treatments at fortnight interval with two targeted treatments in between. then data collection after 30 days
Block C / Treatment C	Two treatments at fortnight interval and data collection after 30 days	Three treatments at 10 days interval and data collection after 30 days	Two treatments at fortnight interval with two targeted treatments in between. then data collection after 30 days

Data Collection

Data were collected using record sheets by two different data collectors who rotated blocks, and for each phase, all data were collected within a day for homogeneity reasons. This was necessary to control for environmental and spatial effects.

Data Processing and Analysis

Data were entered using EpiData Version 3.1 (EpiData Association, Odense Denmark, 2008) and analyzed using the Statistical Package for Social Sciences (SPSS) Standard version, Release 21.0 (IBM Inc. 2012). Data were explored for outliers in SPSS using boxplot. Data were first of all screened for normality using Kolmogorov Smirnov and Shapiro Wilk tests. The outcome of these two tests determined whether a parametric or non-parametric test was to be used to compare groups for significant difference. These two tests using the measures of central tendencies and dispersion assume a theoretical normal distribution for the data and plot the real distribution against this theoretically-assumed normal distribution. A non-significant asymptotic significant (P-value > 0.05) is expected for the distribution of a variable to be assumed not deviating significantly from the theoretically-assumed normal model. In the other sense, the real distribution shall not deviate significantly from the theoretically-assumed normal distribution that logically follows the Gaussian shape (Nana, 2018). The normality assumption was violated as depicted on table 2 for all the variables. The non-parametric Kruskall-Wallis test was then used to compare groups for significant difference. Case summaries statistics included Mean, Standard Error of Mean (SEM), Standard Deviation (SD), Minimum value (Min), Maximum value (Max), and the Median. The Percentile values were outlined by the Boxplots. All statistics were discussed at the 95% Confident Level (CL), which implies considering an Alpha Value of 0.05 serving as cut-point for the discussion **of the asymptotic significant values (P-values / Sig.).**

Table 2: Test of normality

Variables	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistics	df	Sig.	Statistics	df	Sig.
Number of black rot pods	0.200	135	0.000	0.749	135	0.000
Number of cocoa pods on the plant	0.124	135	0.000	0.830	135	0.000
Percent black rot pods	0.178	135	0.000	0.837	135	0.000

Results

Table 3: Variation of black-rot-pod intensity across treatment phases within and across treatments

Treatment	Treatment phase	Percent black rot pods						
		N	Mean	Median	SEM	Min	Max	SD
Treatment A	(I) Treatment every fortnight	15	24.9	22.2	2.7	13.7	48.8	10.5
	(II) Treatment every 10 days	15	20.1	20.0	1.4	10.7	28.6	5.4
	(III) Treatment every fortnight with two targeted treatment in between	15	17.7	13.7	3.5	0.0	50.0	13.5
	Total	45	20.9	20.0	1.6	0.0	50.0	10.5
Treatment B	(I) Treatment every fortnight	15	24.6	22.9	4.8	3.6	60.3	18.5
	(II) Treatment every 10 days	15	13.0	15.4	2.7	0.0	35.7	10.3
	(III) Treatment every fortnight with two targeted treatment in between	15	14.0	15.4	1.9	0.0	25.0	7.2
	Total	45	17.2	16.7	2.0	0.0	60.3	13.7
Treatment C	(I) Treatment every fortnight	15	44.9	38.6	8.0	2.6	129.0	31.2
	(II) Treatment every 10 days	15	40.2	34.9	4.0	16.9	72.7	15.5
	(III) Treatment every fortnight with two targeted treatment in between	15	20.9	20.0	2.6	7.5	50.0	10.0
	Total	45	35.3	30.6	3.4	2.6	129.0	23.0
Total	(I) Treatment every fortnight	45	31.4	23.1	3.5	2.6	129.0	23.4
	(II) Treatment every 10 days	45	24.5	21.1	2.4	0.0	72.7	16.0
	(III) Treatment every fortnight with two targeted treatment in between	45	17.5	16.7	1.6	0.0	50.0	10.7
	Total	135	24.5	20.0	1.6	0.0	129.0	18.2

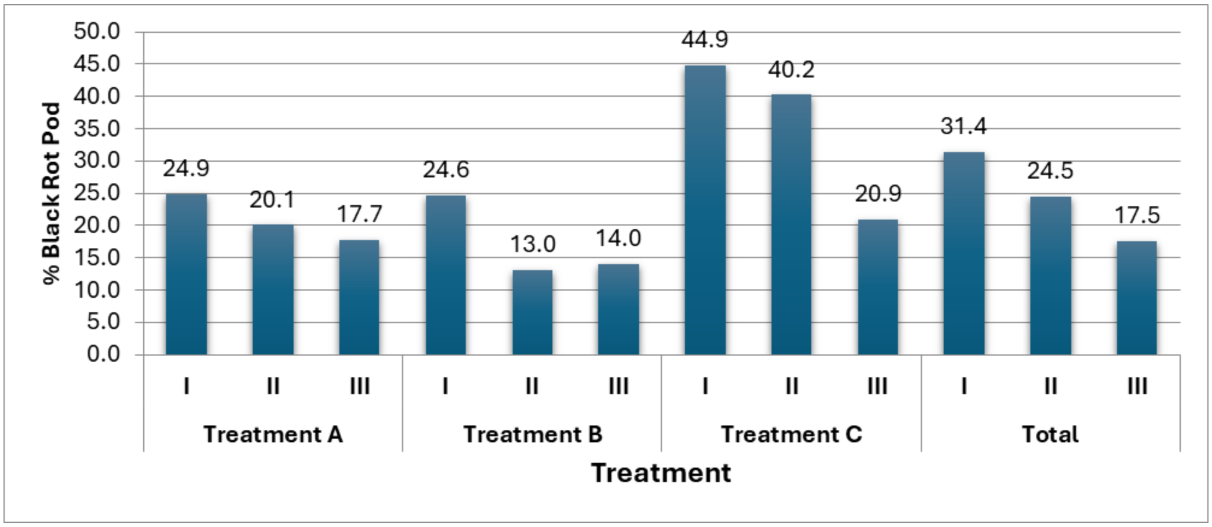
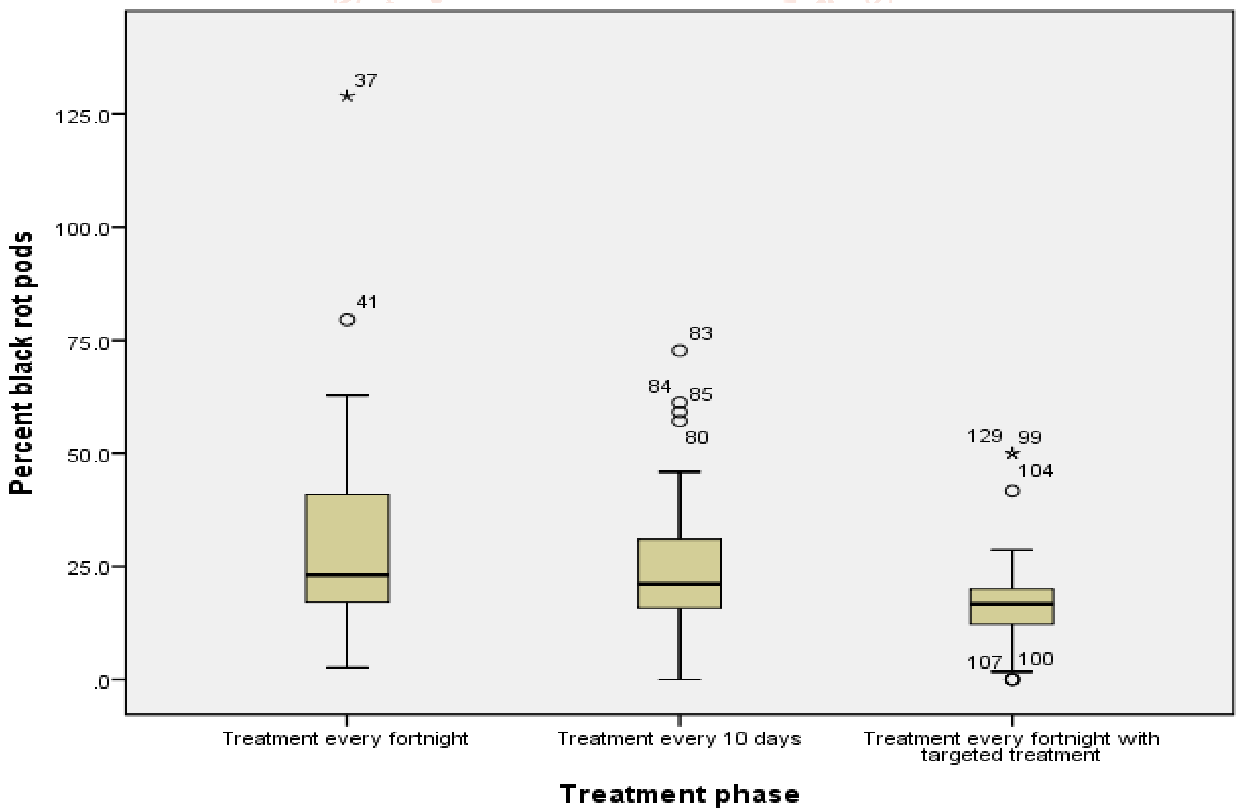


Figure 1: Variation of black-rot-pod intensity across treatment phases (I, II & II) within and across treatments (A, B & C).

In overall, there was a drop in black rot cocoa pods across the phases with phase III (treatment every fortnight with two targeted treatments in-between and data collection after 30 days) showing the most efficient, with an average percentage of losses due to black rot pods of 17.5%. This was followed by the phase II (three treatments at 10 days interval and data collection after 30 days) with a percentage of losses due to black rot pods of 24.5%, while phase I (two treatments at fortnight interval and data collection after 30 days) was the least efficient in controlling black rot pods with a percentage of losses of 31.4%, and this difference was statistically significant (KWT: P=0.001). Comparing within treatment, the trend was the same, with Phase III approach being the most efficient and Phase I the least (table 3, figure 1 & 2). The dispersion of the values was equally the least with phase III, having the smallest range (50.0) and the smallest SD (10.7), table 3.



Kruskal Wallis Test: H=13.478; P=0.001

Figure 2: Variation of black-rot-pod intensity across treatment phases

Table 4: Multiple comparisons among treatment phases

Dunnett C					
(I) Treatment phase	(J) Treatment phase	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Treatment every fortnight	Treatment every 10 days	6.9822	4.2199	-3.253	17.217
	Treatment every fortnight with two targeted treatments in-between	13.8933*	3.8283	4.608	23.179
Treatment every 10 days	Treatment every fortnight	-6.9822	4.2199	-17.217	3.253
	Treatment every fortnight with two targeted treatments in-between	6.9111	2.8660	-.040	13.862
Treatment every fortnight with two targeted treatments in-between	Treatment every fortnight	-13.8933*	3.8283	-23.179	-4.608
	Treatment every 10 days	-6.9111	2.8660	-13.862	.040

*. The mean difference is significant at the 0.05 level.

Multiple comparisons among the tree phases shows that there was a significant difference between Phase I and Phase III (P<0.05) but not between Phase I and Phase II (P>0.05). Phase II approach did not differ significantly from the other two (P>0.05). Phase III differed significantly from Phase I approach (P<0.05) but not from phase II (P>0.05), though more efficient than the later (table 4).

Discussion

Ndoumbe-Nkeng et al. (2003) equally found that the cultural practice of phytosanitary pod removal was potentially efficient as control method before recommending that it would need to be associated with other control methods to establish an integrated management system for cocoa farmers. In this study context, phytosanitary pod removal was not managed as a confounder but as a support strategy to minimize losses. In fact, in this study context, pod-rot control was based on fungicide application following the set experimental plan, reason why phytosanitary pod removal was generally applied and the same way. The efficiency of phytosanitary pod removal was earlier acknowledged by several authors (Muller, 1974; Tondje et al., 1993); Soberanis et al., 1999; Oduro et al., 2020; Merga, 2022; Ndoumbe-Nkeng, 2003), reason why it was highly considered in this study context in prospect of integrated management. Though it was recorded a drop in black rot cocoa pods across the phases with phase III leading with 17.5% losses due to black-rot cocoa pods, this is still considerable loss, which could be explained by heavy rainy weather condition with rain falling almost 5 days out of 7 a week over the experimental period. Vanegtern et al. (2015) equally ascertained that environmental conditions can be a major confounder to chemical control. In this very vein, Acebo-Guerrero et al. (2012) emphasized that the results of cocoa black-rot pod control may depend on cacao-growing region. Targeted treatment was also recommended by Merga (2022) in an integrated-disease-management approach. The 17.5% losses due to black-rot of cocoa pods recorded in Phase III experiment appeared relatively good if we take from usual critical rates reported (Dormon et al., 2004; Hebbar, 2007; Adomako, 2007).

Conclusion

The study aimed at appraising the comparative effect of three approaches of fungicide control of cocoa black-pod-rot disease on mountainous humid cocoa farm in Kékem, Cameroon. The experimental design consisted of the three approaches of treatment applied to three different fungicides distributed at random to three blocks. Phase I consisted of treating every two weeks, Phase II every 10 days and Phase III every two weeks with targeted treatment in between two treatments. Phase III proved to be more efficient and moreover consuming the lesser amount of fungicide as compared to phase II. Though the consumption of fungicide was the least in Phase I, the losses were 13.9% higher as compared to Phase III, which is a conservative-proportionate increase of 79.4%. This gain in fungicide was too far from economically compensating the losses, thus making Phase III approach the most cost-effective as it even consumed lesser fungicide as compared to Phase II.

Recommendations

Based on the findings of this study, it was recommended that spacing fungicide application in the control of cocoas black-rot-pods coupled with targeted treatment for critically affected spots reduced not only the intensity of rotten pods but equally consumed lesser fungicide with major advantages for the environment while been economically cost-effective. Phytosanitory removal of rotten pods was generally applied in prospect of integrated disease control, which is an added value for sustainable farming system.

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