International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 10 Issue 5, Sep-Oct 2026 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Comparative Effect of Three Approaches of Fungicide Control of Cocoa Pod Rot Reinforced with an Anti-Capsid Insecticide on Mountainous Humid Cocoa Farm in Kekem, Cameroon: A Meta Study

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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 impact of cocoa agro-industry on global development cannot be underestimated. The agricultural policy of Cameroon has long prioritized cocoa, thus acknowledging its enormous contribution to the gross domestic product (GDP), and this has fostered the expansion of the sector. Unfortunately, the cocoa producers, mostly small-scale farmers, have to face with pod rot generally attributed to the fungi *Phytophthora megakarya*, in a context where pierce-sucker insects and borers are also of great contribution.

Aim:
The study aimed at comparing the effect of three approaches of the control of cocoa pod-rot using fungicides reinforced with an anti-capsid insecticide on mountainous humid cocoa farm in Kékem, Cameroon, comparatively to a preliminary study (Nana and Signé, 2024) whereby only fungicides were used.

Methodology:
It was a meta-study whereby the experimental design consisted of three phases (approaches) of treatment applied to three different fungicides distributed at random to three farm blocks for the first arm of the study (study I) as reported by Nana and Signé (2024) and then reinforced with an anti-capsid for the second arm of the study (study II) following the same experimental layout. 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 while Wilcoxon Sign Ranks Test (WSRT) statistically established the significant difference between the first and the second study (study I Vs study II).

Results:
In overall, there was a drop in cocoa pod-rot across the phases with phase III being the most efficient, with an average percentage loss due to pod rot of 6.1% and this difference was statistically significant (KWT: P=0.001). This rate of losses was significantly lower compared to the 8.1% realized during study I (WSRT: 0.001).

Conclusion:
Phase III approach proved to be more efficient and moreover consuming the lesser amount of fungicide as compared to the others during study I and II and reinforcement with an anti-capsid has proven to be more efficient. Though the consumption of fungicide was the least in the first phase, the losses were 6.2% higher as compared to Phase III, which is a conservative-proportionate increase of 51.9%. This gain in fungicide was too far from economically compensating the losses, thus making Phase III approach the most cost-effective, and this

How to cite this paper: Nana Célestin | Stéphanie Signé Mamba "Comparative Effect of Three Approaches of Fungicide Control of Cocoa Pod Rot Reinforced with an Anti-Capsid Insecticide on Mountainous Humid Cocoa Farm in Kekem, Cameroon: A Meta Study" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-10 | Issue-5, October 2026, pp.1671-1684, URL: www.ijtsrd.com/papers/ijtsrd142335.pdf

IJTSRD142335

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edge was maintained during the second study where fungicides were reinforced with an anti-capsid. The obvious decrease in the rate of rotten pod comparatively to the first arm of the study whereby only fungicides were used coupled with the increase in pod load over all the phases testified of the obvious contribution of pierce-suckers to the losses due to pod rot.

Recommendations:
It was recommended that spacing fungicide reinforced with anti-capsid application in the control of cocoa pod rot coupled with targeted treatment for critically affected spots reduced not only the intensity of rotten pods but equally consumed lesser pesticide with major advantages for the environment while been economically cost-effective. Phytosanitary removal of rotten pods was generally applied in prospect of integrated pod-rot control, which is an added value for sustainable farming system.

KEYWORDS: *Fungicide, anti-capsid, control, cocoa, pod-rot, meta-study, humid mountainous farm, 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. Besides fungi attacks, the production of cacao is threatened by diversified and enormous amount of insects and plant pathogens that pose threats to the health of the trees as well as the yield of the beans (Destructive insects that pierce young cocoa shoots, buds, and pods to suck sap can lead enormous losses and sometimes affecting an entire cocoa tree. This feeding creates black lesions, deforms young pods (cherelles), and causes shoot dieback, threatening major yield losses across West and Central African farms (Tumanjong and Rai, 2014). These pests include cacao mealybugs, cacao aphids, cacao thrips, whiteflies and spider mites, in a nutshell, various insect pests belonging to the orders of Lepidoptera, Coleoptera, Diptera and Hemiptera (Ayenor et al., 2007; Ferrari et al., 2014; Saripah, 2014) The socio-economic impact of cocoa pod rot is enormous as the majority of farmers in Central Africa and West Africa as well are small-scaled farmers (Vos & Krauss, 2004; Ayenor et al., 2007) and the effective field action by extension intervention workers significantly increase farmers' awareness and ability to control capsids in Ghana (Ayenor et al., 2007). Biological control methods were also recommended whereby three alternative control methods were tested with farmers: mass trapping, using sex pheromones; applying crude aqueous neem Azadirachta indica A. Juss. (Meliaceae) seed extract (ANSE) and using the predatory ant Oecophylla longinoda Latreille (Hymenoptera: Formicidae) as a biological control agent. Contrary to most previous reports, studies on temporal distribution of cocoa capsids indicated that the population peaked in March. ANSE was effective against capsids and other cocoa insect pests and did not affect the predatory ant (Ayenor et al., 2007). Biological control methods have been proven efficient in managing pests that affect cocoa pods (Saripah, 2014; Siswanto et al.; 2020). Generally, pest control in cocoa plants, farmers still use chemical insecticides. Inappropriate use of chemical insecticides will have a bad impact, more detrimental than the benefits generated, such as can cause pest resistance, the emergence of secondary pests, environmental pollution and product rejections due to residual problems that exceed the tolerance threshold (Siswanto et al.; 2020). Though black ants has proven to be efficient predator in controlling cocoa pod borer, it is worth noting that ants are also detrimental to yield as they strip cocoa pods to build shelter for themselves, exposing them to diseases (fungi, bacteria, viruses) and other pests' attacks.

Objective of the study

The study aimed at comparing the effects of three approaches of fungicide control reinforced with and anti-capsid on cocoa black-pod-rot 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

This was a meta-study. In study I that was carried out in 2024 (Nana and Signé, 2024), 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. In study II carried out in 2026, the same experimental layout was applied, but this time around, the fungicides were all reinforced with an anti-capsid insecticide. From study I to study II, the farming system has been the same, manual clearing with no application of fertilizer.

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 & 3 for all the variables and for the two studies. The non-parametric Kruskall-Wallis test was then used to compare groups for significant difference within study groups while Wilcoxon Sign Ranks Test (WSRT) was used to compare between Study I and II. 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. Treatment efficiency the same as in study I (Nana and Signé, 2024), was estimated by direct weighting of the number of rotten pods against the number of sound pods, instead of using the conservative proportionate scale than seems to underestimate the weight of damage. For instance, 30% of rotten pods means they were 70% more sound pods than rotten pods and 110% of rotten pods means they were 10% more rotten pods than sound pods. 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 for study I

Variables	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Number of sound cocoa pods on the plant first study	0.124	135	0.000	0.830	135	0.000
Number of rotten pods first study	0.200	135	0.000	0.749	135	0.000
Total number of pods first study	0.127	135	0.000	0.845	135	0.000
Percent rotten pods first study	0.178	135	0.000	0.837	135	0.000

Table 3: Test of normality for study II

Variables	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Number of sound cocoa pods on the plant second study	0.128	135	0.000	0.872	135	0.000
Number of rotten pods second study	0.149	135	0.000	0.867	135	0.000
Total number of pods second study	0.128	135	0.000	0.881	135	0.000
Percent rotten pods second study	0.111	135	0.000	0.900	135	0.000

Results

Table 4: Variation of rotten-pod intensity across treatment phases within and across treatments in study I

Treatment	Treatment phase	Percent rotten 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 treatments 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 treatments 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 treatments 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

Table 5: Variation of rotten-pod intensity across treatment phases within and across treatments in study II

Treatment	Treatment phase	N	Mean	Median	SEM	Min	Max	SD
Treatment A	Treatment every fortnight	15	13.3	10.5	2.3	4.7	40.0	8.9
	Treatment every 10 days	15	19.1	20.0	1.9	8.9	31.8	7.5
	Treatment every fortnight with targeted treatment	15	5.4	4.6	1.5	0.0	17.4	5.7
	Total	45	12.6	10.5	1.4	0.0	40.0	9.3
Treatment B	Treatment every fortnight	15	11.9	11.0	1.6	4.0	26.2	6.2
	Treatment every 10 days	15	7.2	3.4	2.1	0.0	23.8	8.2
	Treatment every fortnight with targeted treatment	15	8.3	6.4	2.4	0.0	30.0	9.5
	Total	45	9.1	9.0	1.2	0.0	30.0	8.1
Treatment C	Treatment every fortnight	15	16.8	14.3	3.7	4.5	60.7	14.4
	Treatment every 10 days	15	17.1	14.5	2.5	6.9	41.4	9.8
	Treatment every fortnight with targeted treatment	15	10.7	9.6	2.4	0.0	26.5	9.3
	Total	45	14.9	11.8	1.7	0.0	60.7	11.6
Total	Treatment every fortnight	45	14.0	11.1	1.5	4.0	60.7	10.4
	Treatment every 10 days	45	14.5	14.5	1.5	0.0	41.4	9.9
	Treatment every fortnight with targeted treatment	45	8.1	6.1	1.3	0.0	30.0	8.5
	Total	135	12.2	10.3	0.9	0.0	60.7	10.0

Table 6: Variation of rotten-pod intensity across treatment phases within and across treatments comparing between study I & II

Treatment	Treatment phase	N	Mean		WSRT (P-value)
			Study I	Study II	
Treatment A	Treatment every fortnight	15	24.9	13.3	0.006
	Treatment every 10 days	15	20.1	19.1	0.551
	Treatment every fortnight with targeted treatment	15	17.7	5.4	0.002
	Total	45	20.9	12.6	0.000
KWT			0.051	0.000	
Treatment B	Treatment every fortnight	15	24.6	11.9	0.004
	Treatment every 10 days	15	13.0	7.2	0.147
	Treatment every fortnight with targeted treatment	15	14.0	8.3	0.090
	Total	45	17.2	9.1	0.000
KWT			0.132	0.136	
Treatment C	Treatment every fortnight	15	44.9	16.8	0.001
	Treatment every 10 days	15	40.2	17.1	0.001
	Treatment every fortnight with targeted treatment	15	20.9	10.7	0.004
	Total	45	35.3	14.9	0.000
KWT			0.001		
Total	Treatment every fortnight	45	31.4	14.0	0.000
	Treatment every 10 days	45	24.5	14.5	0.000
	Treatment every fortnight with targeted treatment	45	17.5	8.1	0.000
	Total	135	24.5	12.2	0.000
KWT			0.001	0.160	0.001

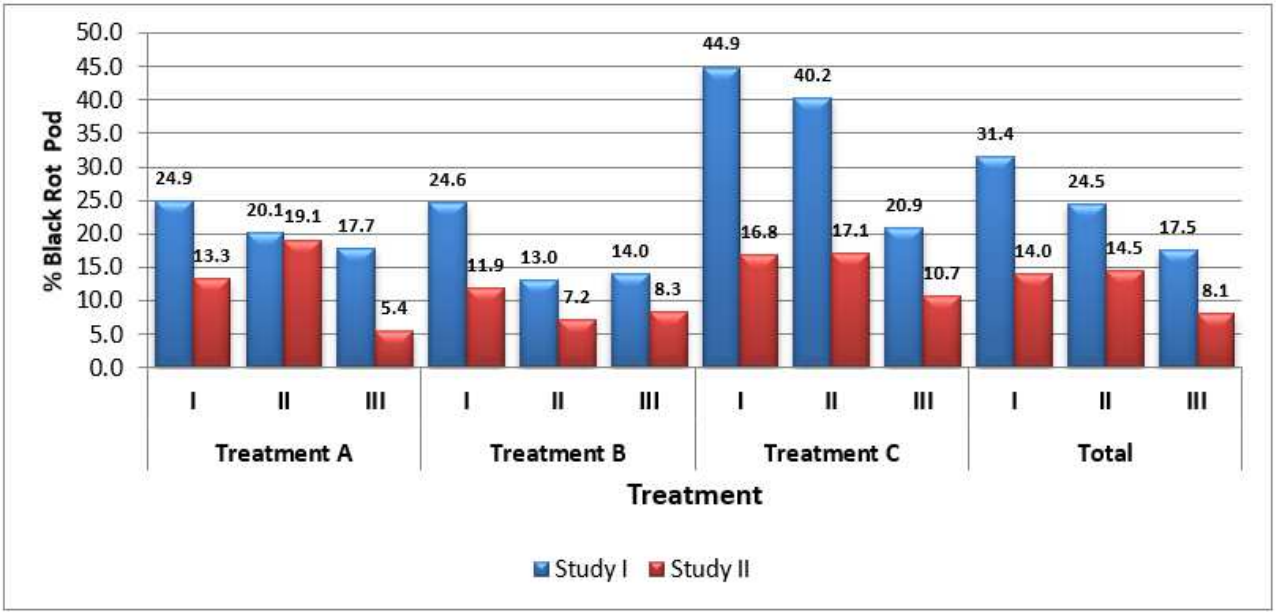
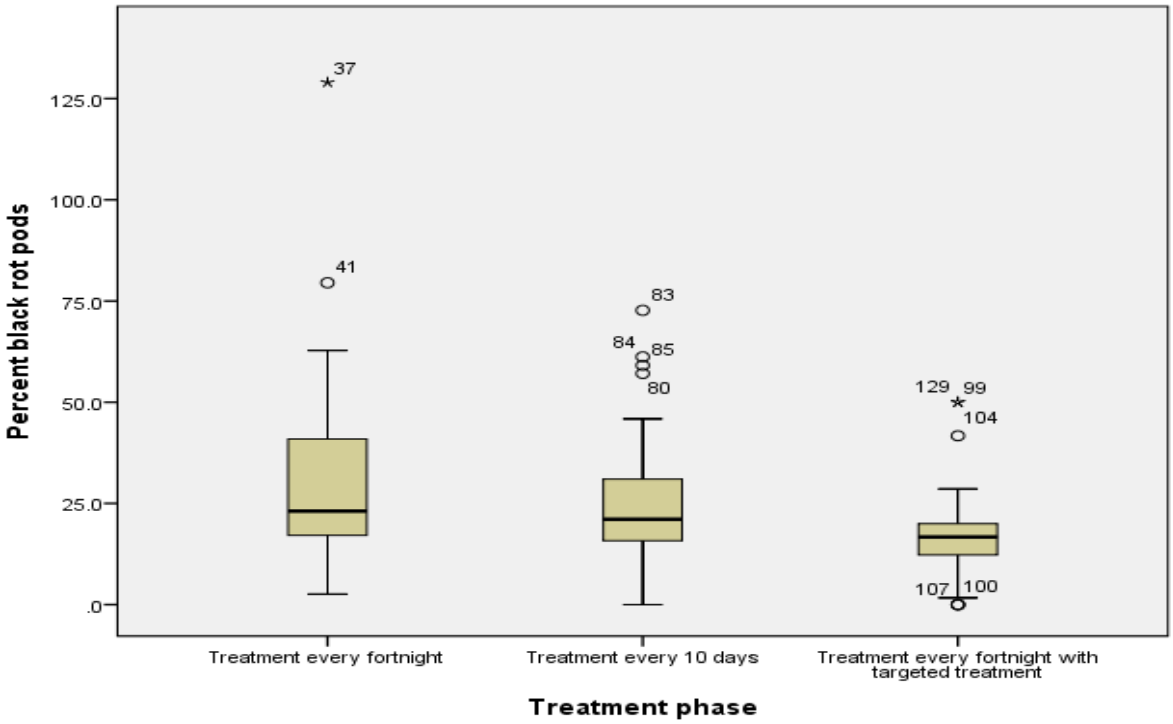


Figure 1: Variation of rotten-pod intensity across treatment phases (I, II & II) within and across treatments (A, B & C) comparing between study I & II.

In study I, in overall, there was a drop in rotten 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 rotten 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 rotten pods of 24.5%, while phase I (two treatments at fortnight interval and data collection after 30 days) was the least efficient in controlling rotten 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.

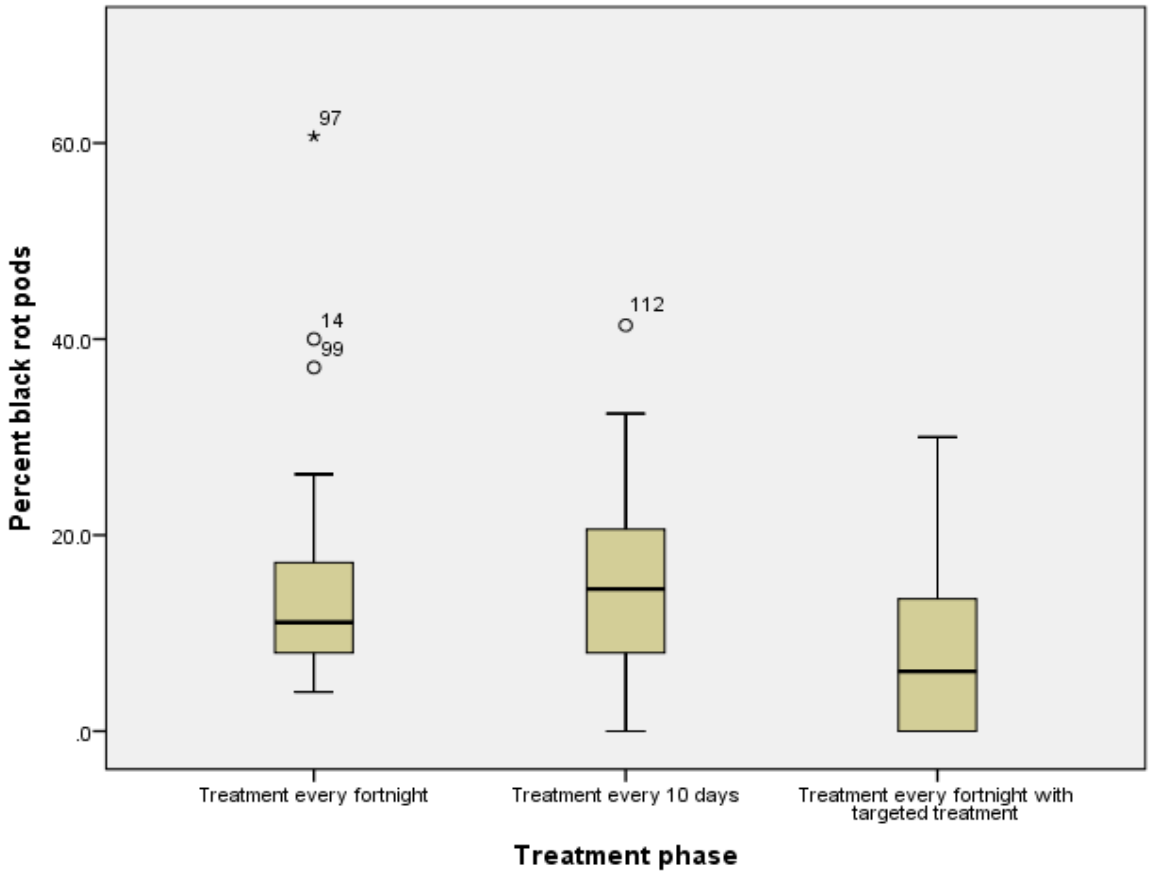
In study II, in overall, there was a drop in rotten cocoa pods across the phases with phase III (treatment every fortnight with two targeted treatments in-between and data collection after 30 days) showing the most efficient, with an average percentage of losses due to rotten pods of 8.1%. This was followed by phase I (Treatment every fortnight and data collection after 30 days) and II (three treatments at 10 days interval and data collection after 30 days) with almost the same (P>0.05) percentage of losses due to rotten pods of 14.0% and 14.5% respectively (table 8). Comparing within treatment, the trend was the same, with Phase III approach being the most efficient and Phase I the least (table 4, figure 1 & 3). The dispersion of the values was equally the least with phase III, having the smallest range (30.0) and the smallest SD (8.5), table 4.

Comparing between study I & II, values were less dispersed in study II than study I (table 4 & 5; figure 2 & 3) and percentages of rotten pods significantly smaller in study II for all the phases and all the treatments (P<0.05) as presented on figure 1 and table 6).



Kruskal Wallis Test: H=13.478; P=0.001

Figure 2: Variation of rotten-pod intensity across treatment phases study I



Kruskal Wallis Test: H=13.875; P=0.001

Figure 3: Variation of rotten-pod intensity across treatment phases study II

Table 7: Multiple comparisons among treatment phases study I

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.					

Table 8: Multiple comparisons among treatment phases study II

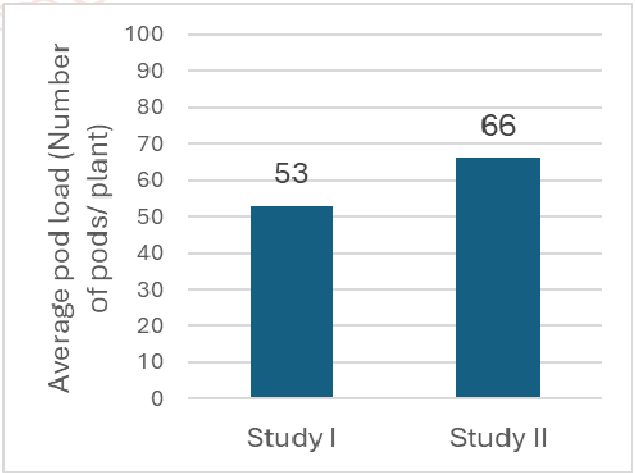
Dunnett C					
(I) Treatment phase	(J) Treatment phase	Mean Difference (I-J)	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Treatment every fortnight	Treatment every 10 days	-.5044	2.1362	-5.686	4.677
	Treatment every fortnight with targeted treatment	5.8822*	1.9961	1.041	10.724
Treatment every 10 days	Treatment every fortnight	.5044	2.1362	-4.677	5.686
	Treatment every fortnight with targeted treatment	6.3867*	1.9408	1.679	11.094
Treatment every fortnight with targeted treatment	Treatment every fortnight	-5.8822*	1.9961	-10.724	-1.041
	Treatment every 10 days	-6.3867*	1.9408	-11.094	-1.679
*. The mean difference is significant at the 0.05 level.					

In study I, multiple comparisons among the three 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).

In study II, multiple comparisons among the three phases shows that there was a significant difference between Phase I and Phase III (P<0.05), Phase II and Phase III (P<0.05) but not between Phase I and Phase II (P>0.05). (table 4).

Comparing between study I & II, for the two studies, there was no significant difference between Phase I and Phase II (P>0.05) while there was a significant difference between Phase I and Phase III (P<0.05). But in study II, unlike study I, there was a significant difference between Phase II and Phase III.

Pod load



WSRT: z=-6.711; P=0.000.

Figure 4: Comparing pod load between study I and II.

The average number of pods per plant was 53 in study I (figure 4), significantly lower than the 66 recorded in study II (P=0.000).

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 rotten 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 8.1% 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). The use of an anti-capsid insecticide in controlling cocoa pests has equally been proven commensurate in increasing yield by Ayenor et al. (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. Integrating the control of pests notably pier suckers besides fungi significantly reduced losses due to pod rot.

Recommendations

Based on the findings of this study, it was recommended that spacing fungicide reinforced with anti-capsid application in the control of cocoa pod rot coupled with targeted treatment for critically affected spots reduced not only the intensity of rotten pods but equally consumed lesser pesticide 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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