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Effect of Artificial Shading on Severity of Coffee Berry Disease in Kiambu County, Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Author RKK designed the study, wrote the protocol gathered the initial data and performed preliminary data analysis. Authors JN, COO and JMK being supervisors, managed the literature searches, anchored the field study, interpreted the data and produced the initial draft. All authors read and approved the final manuscript.

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ABSTRACT

Coffee Berry Disease (CBD), caused by the fungus *Colletotrichum kahawae,* is a major constraint that hinders Arabica coffee production in Kenya. The disease causes up to 80% coffee losses thus affecting export earnings and food security in Kenya. *Colletotricum kahawae* is spread by raindrop splashes on unprotected trees and excessive wetness in the coffee bush. This study assessed the specific effect of artificial shading on the development and progression of *C. kahawae* in a commercial farm in Riabai area of Kiambu County in Kenya. The study was formulated out of the realization that the commonly used fungicides for protecting the crop were expensive and hazardous to the environment. International legislation on chemical residue levels is also becoming stringent in most coffee consuming countries. The experiment was laid out in a three replicate Randomized Complete Block Design. There were four treatments comprising of (i) four pruned and artificially shaded coffee trees; (ii) four shaded and unpruned trees; (iii) four pruned and unshaded

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trees and (iv) four unpruned and unshaded trees. Data was recorded on diseased berries, losses due to physiologic fall and total losses due to both and expressed as percentage of the total berries. The data was subjected to Analysis of Variance (ANOVA) using general linear model (GLM) on COSTAT software. Treatment means were separated using Duncan's Multiple Range Test at P≤0.05. The results showed that artificial shade significantly reduced development and progression of CBD. The major finding of this study is that shade is an important cultural practice in the management of CBD. It is recommended that growing coffee under agroforestry system where artificial shade is substituted with shade trees will be more beneficial to the small holder farmer.

Keywords: Arabica coffee; coffee berry disease; Colletotrichum kahawae; artificial shading.

1. INTRODUCTION

Coffee Berry Disease (CBD) caused by *Colletotrichum kahawae* [1,2] impedes Arabica coffee production in Kenya and other Arabica coffee producing countries in Africa [3]. *Colletotrichum kahawae* belongs to the recently voted eighth important group of plant pathogenic fungi in the world [4]. Coffee berry disease was first reported in Kenya in 1922 near Soy and Turbo in Western Kenya, close to the boarder of Uganda [5]. The disease led to the destruction and abandonment of Arabica coffee plantations in some of those areas. The disease then spread southwards and eastwards and by late 1930's all high altitude areas west of the Rift Valley were affected [5]. The disease causes yield losses of up to 80% when the environmental conditions for its development prevails [6]. These coffee losses have been attributed to a number of factors especially poor management practices and has continuously become a problem for coffee production in the entire Riabai area of Kiambu County in Kenya and across the African continent [3].The pathogen is an Ascomycota that reproduces sexually and asexually [7]. The asexual spores called conidia are produced within an acervulus [8]. In the field, the disease attacks coffee berries from flower to ripe berry, though most damage is done when young expanding berries are infected which drop prematurely after being diseased [9,10]. When infection progresses into the coffee beans, the resultant mummified berries have no economic value (plate 1) [7]. Beans from infected berries are of inferior quality or in most cases are completely destroyed. Ideal conditions for *C. kahawae* development are high humidity, relatively warm temperatures, and high altitude [2].

Plate 1. Coffee berry disease symptoms at onset of infection on green berries (shown by white arrow) and at advanced stage on black mummified berries (shown by red arrow)
Source: Researcher, 2015

Of the cultivated species of coffee, *Coffea arabica* is by far the most important and is the lone existing host for *C. kahawae* is *C. arabica* [11]. It represents over 65% of the total area in the world used for coffee production. Kenya principally produces Arabica coffee that is known worldwide for its fine quality and is used to blend other coffees of inferior quality from other origins [9]. Most coffee growers in Riabai area of Kiambu County are small scale farmers and are dependent on fungicides to control CBD. Chemical control is expensive and beyond reach of most small scale farmers [12]. The recommended chemical spray programme targets at constantly protecting the crop throughout the berry development stage [13], but fewer sprays which are usual with small scale farmers only help to aggravate the disease [12]. In addition, sun grown coffee requires more chemical inputs, and these expenses hampers rather than help small farmers. The application of a fungicide prior to contact between pathogen and host is considered to be preventative while application after inoculation and just before initial symptoms is curative. Curative fungicides are active against pathogens that have already infected the plant but they tend to have a higher risk of pathogens developing resistance to the fungicide currently, chemical residues are the subject of legislation in most coffee consuming countries [14].

In the framework of the country's sustainable development, agriculture and the entire agri-food sector incorporates more ecofriendly plant technology aspects by limiting the use of chemical. Coffee trees sited under natural shade of fruit trees are considerably less infected than those situated in full sunlight [14]. In addition, berries on the leafless parts of branches, near the main trunk of the coffee tree, will be less infected than those on leafy sections. Shade tends to alter the microclimate and soil properties in coffee plantations, thus directly or indirectly affecting disease development, and control inoculum dispersal. Growing of coffee under shade plants (not trees) also help to curb the disease by forming a physical barrier [14]. Changes in the economics of coffee are already leading to producers to reduce dependency on agrochemicals thereby increasing use of shade [15].Cultural disease control methods are therefore understood to minimize CBD incidence and hence this project is formulated to investigate artificial shading as some of the practices that can control CBD.

Artificial shading using 50% has been carried out on seedlings or small plants in analysis of effects of solar radiation on vegetative growth and photosynthesis of crop plants than field experiments on crops with natural shade. Equally, studies have been carried out on the influence of natural shading on CBD development in Cameroon [16]. However, artificial shading particularly using 55% shade net, had not been carried out on mature plants and how it influences CBD development and progression. This probed this investigation in attempt to fill the gap on the effects of artificial shading on development and progression of CBD. The ministry of agriculture, through the extension officers will disseminate the research results to farmers in order to achieve practical and sustainable coffee production.

2. MATERIALS AND METHODS

2.1 Research Site

This research was conducted in a selected farm in Riabai area of Kiambu County in Kenya (1,734 m above sea level, 1° 10' 0" South, 36° 50' 0" East). The area represents the Upper midlands with high incidence of CBD.

2.2 Sample Size and Sampling

The experiment was conducted on an existing coffee field that was approximately 1200 square meters. The field was selected at random following a line transects as a representative of coffee farms in Riabai area of Kiambu County. Experimental plots were demarcated at intervals of 10 meters based on topography.

The study was carried out on already mature SL28 variety of *C. arabica* that was about 17 years old. Four coffee trees were selected for each treatment using random sampling method.

2.3 Experimental Design and Layout

The trial was laid out in a three-replicate Randomized Complete Block Design (RCBD). Four trees were selected and given the following treatments: - (i) shaded and pruned, (ii) shaded and unpruned, (iii) unshaded and pruned, (iv) unshaded and unpruned. On the third week after flowering, three branches were carefully marked on each of the four trees in all the treatments (Plate 2). Marking was done at two points by use of synthetic plastic material and indelible ink. Data collection was concentrated on the marked points only, while the rest of the sections of the tree were subjected to normal field practices.

There was natural shade in the field which was pruned before putting up the artificial shade. The artificial shade was provided with a regular mesh allowing 55% of the light to filter through (Plate 3). The net was suspended on four posts at a height of 3 meters and kept in position using rafters on which strings were tied and fastened to keep it in place. For each replication, two treatments of four trees each were artificially shaded. The other two treatments of equal tree numbers were unshaded. Of the two shaded treatments in each replication, one was pruned and the other was un-prunned. The same was repeated on the remaining two unshaded treatments.

Plate 2. Marked branch which was consistently used in data collection
Source: Researcher

Plate 3. Artificial shade lay using a black shade net 55%
Source: Researcher

2.4 Data Collection

Upon flowering and formation of coffee berries, CBD infection was recorded on three marked branches, located on the upper, middle and lower storeys respectively. In order to have correct measurement of *C. kahawae* development and progression on the branches, counting of infected berries as a proportion of total berries on each marked branch was done on weekly basis. Data recording commenced from sixth week after flowering and continued on weekly intervals up to twentieth week, that is, from April to August 2015.

Berries which dropped as a result of physiological fall were also recorded. The loss of berries due to both CBD and physiological fall was recorded as total loss. On every subsequent week the number of infected berries was counted and cumulated with those recorded the previous week. Records were obtained for (i) the total number of berries (Btot), (ii) the number of newly diseased berries, marking them with small labels to avoid including them in subsequent counting (Bdis), and (iii) old diseased berries (already marked) (Bmark) and expressed as a percentage of the total berries. The different harvest losses were estimated in the three categories as follows:

(a) The percentage of total losses (PtotL) observed throughout the research period. These losses included those due to CBD and physiologic fall. It was calculated by the formula; PtotL = [$\mathrm{Btot\_1}$– (Btotn – Bmarkn – Bdisn)/$\mathrm{Btot\_1}$] × 100 (n-20); Where, Btot_1 indicated the total number of berries on the first inspection and the expression (Btotn – Bmarkn – Bdisn) the number of healthy berries in the last week of observations. The terms Btotn, Bmarkn, and Bdisn represented the total number of berries, the total number of marked diseased berries and the total number of newly infected berries on the final observation and inspection respectively. (b) The percentage of diseased berries (Pdis) was the ratio between the sum of newly diseased berries counted over all the weeks of observations (ΣBdis1 – n) and the initial number of berries (Btot_1): Pdis = (ΣBdis1 – n/Btot1) multiplied by a hundred. (c) The percentage of losses not due to physiologic fall (Pfall) was expressed by the difference between total losses and losses due to CBD (Ploss – Pdis) [16]. These two variables were calculated for the observation attained in each week.

2.5 Data Analysis

The week with highest CBD infection on unshaded and unpruned control experiment was chosen to represent the peak CBD infection. The peak CBD infection data for all treatments was subjected to analysis of variance (ANOVA) using general linear model on COSTAT Statistical software [17]. The treatment means were separated by Duncan's Multiple Range Test at $P \leq 0.05$. The same analysis was applied for Physiological Fall and Total Berry Loss. Progression of CBD was plotted on graphs from the sixth week to twentieth week.

3. RESULTS

3.1 Coffee Berry Disease Infection

Results presented in Table 1 indicate that CBD infection was significantly influenced by shade ($p \leq 0.05$). The main effects of canopy management and storey had no significant effect on CBD infection. All the two way (shading x canopy management, Shading x Storey and Canopy Management x Storey) and three way (Shading x Canopy Management x Storey) interaction effects had no significant effect on CBD infection. CBD infection was higher in unshaded coffee with a mean of 57.40% compared to shaded coffee with a mean of 45.08% (Table 2).

3.2 Physiologic Fall

Physiologic fall was not significantly affected ($P > 0.05$) by the main effects of shading, canopy management or storey level (Table 1). All the interaction effects, shading x canopy management, Shading x Storey, Canopy Management x Storey and Shading x Canopy Management x Storey, were also non-significant ($P > 0.05$).

3.3 Total Loss

Shading and canopy management significantly affected ($P \leq 0.05$) the total loss due to both CBD infection and physiologic fall (Table 1). Level of storey had no significant effects on the total loss of the coffee berries. Results in Table 2 indicated that the total berry loss was higher in unshaded coffee (75.73%) than shaded coffee (63.65). Unprunned coffee also recorded higher total loss at 74.96% than pruned coffee at 64.42%. All the interaction effects were not significant ($P > 0.05$).

Table 1. Analysis of variance for percentage losses caused by CBD infection, physiological fall and total loss

Source of variation	Degree of freedom	Percent CBD infection		Percent physiological fall		Percent total loss	
		Mean squires	Probability	Mean squires	Probability	Mean squires	Probability
Reps	2	2.51	0.99^{ns}	150.85	0.11^{ns}	126.16	0.56^{ns}
Main effects							
Shading	1	1365.59	0.02*	0.54	0.93^{ns}	1311.88	0.02*
Canopy management	1	400.40	0.17^{ns}	135.06	0.15^{ns}	1000.56	0.04*
Storey	2	170.48	0.44^{ns}	19.03	0.74^{ns}	84.56	0.67^{ns}
Interaction							
shading×canopy management	1	840.51	0.05^{ns}	7.54	0.73^{ns}	688.83	0.08^{ns}
shading×storey	2	301.50	0.24^{ns}	62.87	0.38^{ns}	403.60	0.17^{ns}
Canopy management×storey	2	141.41	0.50^{ns}	34.67	0.58^{ns}	279.93	0.28^{ns}
shading×canopymanagement×storey	2	91.98	0.64^{ns}	74.74	0.32^{ns}	332.22	0.23^{ns}
Error							

*Key: ns = not significant * = Significant at P≤0.05*

Table 2. Comparison between harvest losses means depending on shade, canopy management and storey

Factor	Percent CBD	Percent physiological fall	Percent total loss
Shade			
Shaded	45.08[b]	18.58[a]	63.65[b]
Unshaded	57.40[a]	18.33[a]	75.73[a]
Canopy management			
Pruned	47.90[a]	16.52[a]	64.42[b]
Unpruned	54.57[a]	20.39[a]	74.96[a]
Storey			
Upper	48.46[a]	19.74[a]	68.21[a]
Middle	55.53[a]	17.23[a]	72.75[a]
Lower	49.72[a]	18.39[a]	68.11[a]

Means followed by the same letter are not significantly different at P≤0.05

3.4 Progression of Coffee Losses Due to CBD Infection, Physiologic Fall and Total Loss (CBD Infection Plus Physiologic Fall Losses)

Progression of losses due to CBD infection, physiologic fall and their combined effects comparatively for the experimental period is presented in Figs. 1a to 1c.

3.4.1 Progression of various coffee berry losses due to percent CBD infection for shaded and pruned, shaded unpruned, unshaded pruned and unshaded unpruned coffee experiments

From results in Fig. 1a, the first diseased berries were observed in the eighth week after flowering for all treatments. All the losses due to CBD infection progressed steadily, up to 14 weeks after flowering, where losses due to CBD infection recorded 26.86%. Beyond the 14th week after flowering, losses was increasing at a decreasing rate, when approximately one percent of new infections and nearly zero percent losses due to physiologic fall were recorded on all the coffee trees. However, a maximum of loss of 37.12% due to CBD infection in shaded pruned experiment, 53.24% berry loss in shaded unpruned, 58.89% loss in unshaded pruned experiment and 55.90% in unshaded unpruned experiment was recorded at week 20 after flowering.

3.4.2 Progression of various coffee berry losses due to physiologic fall for shaded and pruned, shaded unpruned, unshaded pruned and unshaded unpruned experiments

From results in Fig. 1b, the first diseased berries were observed in the seventh week after flowering where 0.34% of berry loss was recorded for the shaded pruned experiment. All the losses due to progressed steadily, up to 14 weeks after flowering, where 15% losses due to CBD infection in artificial shaded with pruning experiment, 14.6%, 17.82% and 18.19% was recorded for the experiment in shaded unpruned, unshaded pruned and unshaded unpruned experiments respectively. Beyond the 14th week after flowering, losses were increasing at a decreasing rate in all the trials, when approximately one percent of new infections and nearly zero percent losses due to physiologic fall were recorded on all the coffee trees. However, a maximum of loss of 20%, 17.1%, 20.05% and 20.73% coffee berry losses was recorded due to physiologic fall for shaded and pruned coffee, shaded unpruned, unshaded pruned and unshaded unpruned experiments, respectively.

3.4.3 Progression of various Total coffee berry losses for shaded and pruned, shaded unpruned, unshaded pruned and unshaded unpruned experiments

From results in Fig. 1c, the first diseased berries were observed in the seventh week after flowering where 0.34% of berry loss was recorded for the shaded pruned experiment. All the losses due to progressed steadily, up to 14 weeks after flowering, where 0.34% losses due to CBD infection in artificial shaded with pruning experiment, 12.74%, 10.52% and 9.49% was recorded for the experiment in shaded unpruned, unshaded pruned and unshaded unpruned experiments respectively. Beyond the 14th week after flowering, losses were increasing at a decreasing rate in all the trials, when approximately one percent of new infections and nearly zero percent losses due to physiologic fall were recorded on all the coffee trees. However, a maximum of loss of 54.22%, 73.3%, 74.83% and 76.62% total coffee berry losses was recorded for shaded and pruned coffee, shaded unpruned, unshaded pruned and unshaded unpruned experiments, respectively.

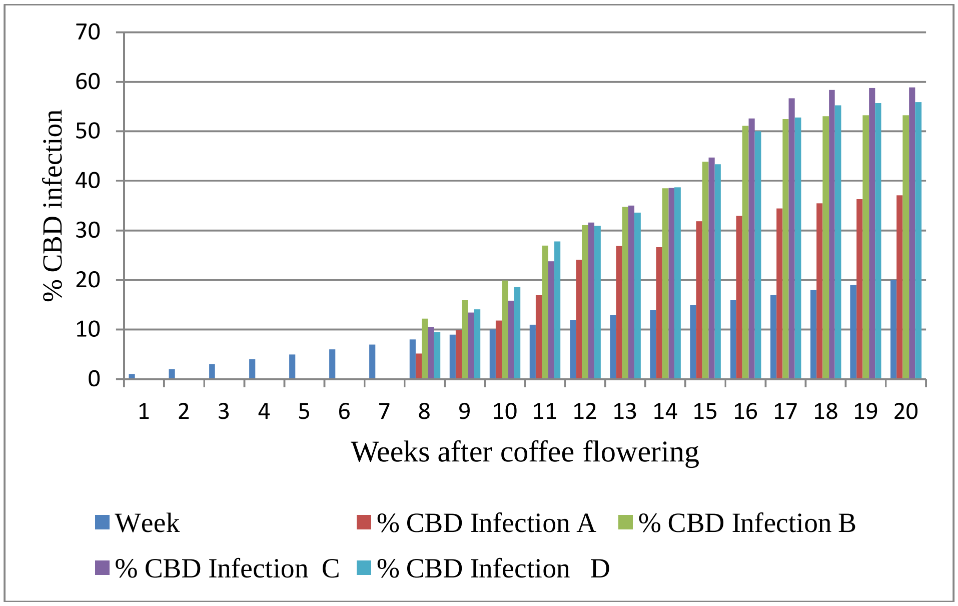

Fig. 1a. Progression of various coffee berry losses due to percent CBD infection for shaded and pruned, shaded unpruned, unshaded pruned and unshaded unpruned experiments

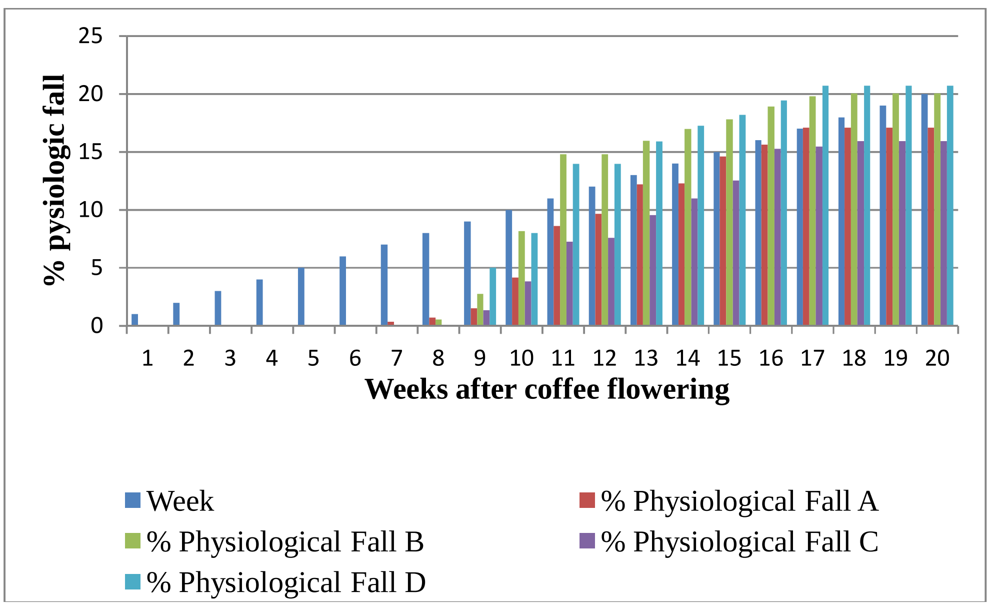

Fig. 1b. Progression of various coffee berry losses due to physiologic fall for shaded and pruned coffee, shaded unpruned, unshaded and unshaded unpruned experiments

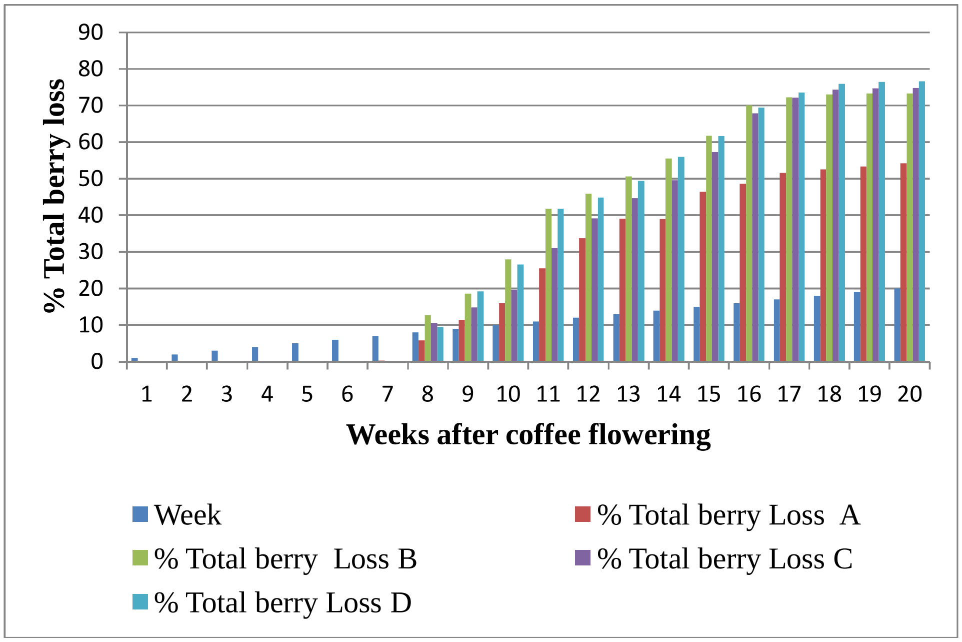

Fig. 1c. Progression of various coffee berry losses due to physiologic fall for shaded and pruned coffee, shaded unpruned, unshaded and unshaded unpruned experiments

4. DISCUSSION

4.1 Effect of Artificial Shading on the Development and Progression of *C. kahawae* Infection, in Riabai Area of Kiambu County, Kenya)

In this study, artificial shading was found to reduce the incidence of CBD on coffee trees when compared to non-shaded coffee. These results are in agreement with the findings of [16], who reported that shading modifies the microclimate of disease development. Artificial shade that was suspended over coffee trees significantly reduced the development and progression of CBD. Shading modifies the micro-ecological conditions and creates a phylloclimate able to interfere with the interaction between pathogens and target organs [18]. Shading also delays fruit development, which may shift the period when coffee berries are more susceptible in relation to the period of high disease pressure [19].

It has also been reported that shading lowers the sunlight, specifically; the ultraviolet-B rays (UVB: 280 – 315 nm) which are necessary for disease development in some plants. Shade also acts as a barrier to conidia dispersal. The canopy intercepts some rain drops while diverting others from their curving line, thus reducing speed of drops that may reach the coffee trees. The drops that reach the coffee tree foliage will have less kinetic energy to dislodge and disperse conidia. Kinetic energy is a significant factor in spore dispersal [19]. From these results, the shade net influence was greatly on the epidemic parameter in *C. kahawae* versus *C. arabica* pathosystem. Shade checked rainfall intensity which in turn, lessened the splash of *C. kahawae* [19].

The level of storey did not affect CBD infection, physiological fall or total berry loss. However, CBD began simultaneously on both sections of the branches, suggesting that the source of inoculum is randomly distributed within the coffee trees. Defoliation due to CLR and drought conditions that prevailed in the field, contributed strongly to lack of significant effect of storey level on CBD infection, physiological fall and total loss. Closeness of the tree branches due to shape of the tree may have also contributed to masking of potential effects. Majority of the branches were located towards the coffee tree canopy, which guided the choice of branches that were studied [19].

5. CONCLUSION

This study confirmed that shading reduces the incidence of CBD on coffee. Artificial shade can be simulated by planting shade trees which can reduce the use of chemicals in controlling CBD. Shading moderates temperature and relative humidity which are the major factors for *C. kahawae* development and progression. Humidity is essential for conidial germination while rainfall is main factor of dispersal [19]. Humidity is essential for conidial germination while rainfall is main factor of dispersal. Therefore, the reduced intensity of rain drops, automatically reduce the rate of conidial splash [19]. This is why shading results in greater benefits to the coffee tree, particularly in marginal regions where it is cultivated.

6. RECOMMENDATION

Arising from this study, the following recommendations have been made:

1. Artificial shade can be simulated/substituted by planting shade trees which can reduce the use of chemicals in controlling Coffee Berry Disease.
2. Further research is recommended to determine the types of real shade trees and shade intensity that would correspond with 55% artificial shade. Also determine how shading affects the quality of coffee beans and beverage.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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