EVALUATION OF BIOSAKYNE, A FORMULATION BASED ON ESSENTIAL OILS FROM *Zingiber officinale* FOR SUSTAINABLE CONTROL AGAINST SUGARCANE SMUT DISEASE CAUSED BY *Sporisorium scitamineum* IN RATOON CROPS.

Abstract: The objective of the present study was to evaluate the effect of treatments of young sugarcane regrowth with a formulation based on the essential oil *Zingiber officinale* on the incidence of *Sporisoriumscitamineum*, on agromorphological parameters and on the technological quality of sugar. The natural fungicide was obtained from a mixture of essential oil of *Zingiber officinale* obtained by steam entrainment of rhizomes. It was sprayed at a rate of 300l/ha by mixing with mineral oil and water. Applications were made to young sugarcane regrowth of the variety NCo376 under natural infestation conditions and other untreated ones served as control. Three applications were made: at 15 days after harvest (T1), at 30 days after harvest (T2) and both times at the same time (T3). Doses of 1500ppm and 2500ppm evaluated at 300l/ha.Agronomic parameters, technological qualities of the cane, and phytopathological descriptors of smut were monitored for 12 months to evaluate the health status of treated and untreated plants. The results showed that the incidence of smut was greatly reduced from 8.67% to 11.17% for treated plants and 20.51% for untreated plants at 1500 ppm and above. The treated plants obtained cane yields largely superior to the control (63,333 kg/ha) ranging from 80,638 kg/ha to 85,500 kg/ha. In addition, they obtained higher sugar yields (between 7.24 and 7.59 t/ha) compared to the untreated plants (5.65 t/ha). This natural fungicide based on the essential oil of *Zingiber officinale* is an alternative to the use of chemicals in the control of Sugarcane smut.
Keywords: Sugarcane smut; *Sporisoriumscitamineum*; biological control *Zingiber officinale*; Côte d'Ivoire

1. INTRODUCTION

The disease known as sugarcane smut is caused by a type of fungus belonging to the family Basidiomycetes called *Sporisoriumscitamineum* [1]. This pathogen has been present in Africa since 1877 from Natal and has spread to all sugarcane production areas since the 1970s [2]. The impact of this disease is noticeable in both the cane yield, which can be reduced by 30 to 50%, and the loss of juice quality [3]. As a result, several highly desired varieties have been removed from plantations due to their high susceptibility to charbon disease [4].In Cote d'Ivoire, sugarcane smut is prevalent in production areas, causing significant production losses [5]. *Sporisoriumscitamineum* produces diploid teliospores that spread via wind, rainwater, and irrigation. These teliospores germinate rapidly in moist and favorable temperature conditions upon contact with sugarcane [6]. The infectious mycelium grows systemically within the plant, preferably settling in each of the formed lateral meristems, disrupting the elongation of the stems, resulting in short internodes, strong tillering, and plant death after the appearance of smut shoots [7]. The fight against plant diseases primarily involves the use of synthetic fungicides such as benomyl, carbendazim, mancozeb, chlorothalonil, propiconazole, and captan [8]. In addition, these fungicides are also paired with thermotherapy treatments to sanitize cuttings [9]. However, these products can be expensive, carcinogenic, and have negative impacts on biodiversity [10]

and [11]. From that point on, the search for alternative, effective, and low-cost methods of control, without any risk to users and protective of the environment, is necessary. The essential oil of *Zingiber officinale* is suspected to have antifungal properties [12]. The objective of this study is to evaluate the response to sugarcane smut disease in plant shoots treated with a formulation based on essential oil of *Zingiber officinale* in order to propose a sustainable alternative to the use of chemical pesticides to producers.

2. MATERIAL ET METHODS

2.1 Study area

The study was conducted in the field at the Borotou-Koro sugar complex site of SUCRIVOIRE company in northern Côte d'Ivoire. The experiments were implemented on Pivot 5 located at N 08 29 919' north latitude and W 007 15 969' west longitude.

2.2 Installation of the experimental system

The experiments were carried out on a 6300 m2 surface area with a length of 100 meters and a width of 63 meters. The plot was divided into four blocks spaced 5 meters apart; each block had 8 rectangular microplots of 120m2. Each microplot consisted of 8 lines of cane, with the central 6 lines being evaluated. All production factors, including land preparation, irrigation, fertilizer application, and weeding, were kept uniform to highlight the effect of the product.

2.3 Preparing natural essential oil fungicide

The essential oil of *Zingiber officinale* was obtained from fresh rhizomes using saturated steam distillation with a Clevenger-type apparatus for 2 hours [13]. This method involves traditional distillation in which the rhizomes do not come into direct contact with water.The rhizomes are arranged on a grid and exposed to a steam current. As the steam passes through, the rhizome cells release the essential oil, which is carried to the condenser and then to the essence collector.The separation is achieved through decantation. The essential oil obtained constitutes the active ingredient in the natural fungicide. To do this, a fixing element (mineral oil) was added at a rate of 5% of the total volume of the formulation, along with an emulsifier (1%), to the essential oil. To do this, a fixing element (mineral oil) was added at a rate of 5% of the total volume of the formulation, along with an emulsifier (1%), to the essential oil. The natural fungicide was evaluated at doses of 1500 and 2500 ppm for a volume of 300 L/ha, which equates to 3.6 liters per micro-plot of 120 m2.

2.4 Applications

The applications were carried out following the methodology described in [14] with slight modifications. Three applications were performed: 15 days after cane harvest (T1), 30 days after cane harvest (T2), and both times (T3). Doses of 1500ppm and 2500ppm were assessed at a rate of 300l/ha. In total, eight treatments combining doses and application time were tested. The spray nozzle of the sprayers was adjusted to a flow rate of 7.03 ml of water per second, and a walking speed of 0.23m/s was determined.The spraying was conducted around and on young regrowth of NCo376 sugar cane variety under natural infestation conditions, with untreated samples serving as control.

2.5 Data collection

2.5.1 Growth and production parameter evaluation

The width and height were measured on the 6 useful rows of each micro-plot. Twelve individual plants were randomly selected from the six useful rows and marked.On these designated stumps, the height of twelve plants was measured using a measuring ribbon from the collar to the V base formed by the last leaves on ten of the plants. At the

3rd and 5th month, the number of stems per stump was determined by counting. After the previous burning before harvest, the number of cane stems were systematically counted on the usable rows. The number of stems per hectare was determined according to the following formula:

$$\text{stem/ha} = \frac{\text{total number of stems x 6667}}{\text{number of useful lines} * \text{length of 1 line}}$$

2.5.2 Cane yield assessment

The trials were conducted for a period of 12 months, which corresponds to the normal duration of the annual sugarcane crop cycle. The useful rows were manually cut and the weight of the canes was determined using a scale suspended from the hook of a mechanical loader. Yield was calculated in tons of cane per hectare by dividing production by the useful area of each corresponding elementary plot, according to the following formula:

$$\text{productivity} = \frac{\text{Mass on usable surface area x 10000}}{\text{usable surface area}}$$

2.6 Évaluation phytosanitaire

2.6.1 Incidences de la maladie du charbon

The incidence of smut was assessed on the 6 useful rows of each microparcel. Twelve strains were randomly chosen on the six useful rows and then marked. The number of stems attacked per strain and the total number of stems were counted in the third and fifth months. The incidence was calculated by dividing the number of diseased plants per strain by the total number of stems per strain [16].

2.6.2Number of shoots per hectare and stem gain

The charcoal shoots were counted on the 6 useful rows of each microplot. Then, the number of shoots was converted to per hectare using the following formula [5]::

$$\text{Number of shoots/ha} = \frac{\text{total number of shoots x 6667}}{\text{number of useful lines} * \text{length of 1 line}}$$

The increase in shoot length was obtained by subtracting the number of charcoal shoot shoots from the treatments and the control group.

2.7 Technological quality assessment

A primary sample of 30 canes taken a few moments after cutting. The sample was ground in a Jeffco mill. Next, 500 g of cane pulp were introduced into a grooved and perforated stainless steel cylinder. Pressure was applied using the press piston, until the pressure gauge stabilized at 100 bar for 1 min.The extracted sugarcane juice was collected in a beaker. The Brix was obtained by depositing a few drops of the juice on the refractometer prism for three readings at 20 °C per treatment [18]. The cane juice's Pol was determined by taking three readings with the saccharimeter and adopting the average as the polarimetry reading. The Schmidt table for the 26 g saccharimeter was used to determine the juice's Pol by multiplying the Pol factor, corresponding to the Brix value, by the Pol value read on the polarimeter.

$$\text{Purity} = (\frac{\text{juice Pol}}{\text{Brix}}) * 100$$

The sugar content was determined by multiplying the Pol of the cane juice by a factor read from a table based on the weight of the 500g pulp cake :

$$\text{Pol \%canne} = \text{Facteurnx Pol jus} * 100$$

2.7.1 Determination of extractable sugar content (ES %)

The extractable sugar rate (SE%) is determined by a formula that considers the sucrose content, fiber rate in the cane, and purity of the sugarcane juice [18]. :$SE\% = [(0{,}85 \times Pol\ \%C)\ (1{,}6 - 60/Pureté) - (0{,}05 \times Fibre\%C)]$

2.7.2 Extractable sugar yield (TSE/ha)

The extractable sugar yield (ESY) was obtained (t/ha) by multiplying the extractable sugar rate value by the cane yield (t/ha) according to the following expression

:$TSE/ha = (SE\ \% * Cane\ yields)\ /100$

2.7.3 Economic evaluation of phytosanitary treatments

The cost of pesticide treatments (CPT) was calculated by adding up the expenses of the cost of essential oils production (CEOP), the cost of inputs (CI), and the cost of field treatment (CFT) using the following formula:

$$CTP\ (F\ CFA) = CPHE + CTC + CI$$

The difference between each treatment and the control group was calculated in order to determine the sugar yield. The cost of the sugar yield (CYS) was obtained based on the market price per kilogram of sugar ($1.40/kg) for each treatment. The gross profit margin (GPM) was obtained by subtracting the sugar sales price (SSP) from the production cost (PC) using the following formula.$MB\ (F\ CFA) = CVS - CTP$

The economic profitability (r), which is the quotient of the profit margin (PM) over the cost of phytosanitary treatment (CPT), has been calculated as follows:

$$r = MB / CTP$$

2.8 Data analysis

An analysis of variance was applied to the measured parameters, and the mean comparison was conducted using the Newman-Keuls test (post-hoc ANOVA test) with a significance level of 5% using STATISTICA 7.1 software.

3. RESULTS

3.1 Agromorphological parameters

3.1.1 Effects on the number of plants per sugarcane strain

Table I displays the number of stems per stump based on treatments. The analysis of the results has revealed a significant difference in stem count values. The stump removal yield did not reveal any difference between the third and the fifth. At the third month, tillering per stump was higher in treatments T1C1, T2C1 and T3C2 than in the control. The number of sprouts obtained ranged from 33.5 to 35.75 sprouts per stump. Treatments T3C1, T1C2, and the mineral oil treatment recorded low numbers of sprouts with 26.50 sprouts per stump, 23.75 sprouts per stump, and 29.25 sprouts per stump, respectively. Conversely, at month 5, treatments T1C2, T1C1, T3C2 and T3C1 had the highest tillering, ranging from 24 to 27 cane stalks per stump, similar to the mineral oil. Treatments T2C2 and T2C1 had the lowest number of stems, similar to the control, at 18.5 stems per stump, 17.75 stems per stump and 21.5 stems per stump respectively.

3.1.2 Effect of treatment with three essential oils on the number of stems/ha

The number of stems per hectare as a function of the treatments is shown in Table II. The analysis of variance identified a difference between the average number of stems per ha. Treated plants recorded a higher average number of stems/ha than non-treated plants. Treatments T2C2, T1C1 and T3C1 produced the highest number of stems per

hectare, fluctuating between 132,386.3 stems/ha and 134,934.0 stems/ha. Treatments T1C2, T2C1 and T3C2 recorded a low number of stems with similar effects to the control (96,224 stems/ha) and the mineral oil treatment (90,300 stems/ha).

3.1.3 Effect of treatments on average plant height

The analysis of variance showed significant differences in the plant heights recorded. Treatments T1C1, T1C2, T3C1, T2C1, and T3C2 had plant heights above the control. The heights obtained for these treatments range from 272.9 cm to 289.9 cm. The observations also revealed that for treatment T2C2, the height was low at 234.5 cm (Figure 1).

3.1.4 Effect of treatments on sugarcane yields

The sugarcane yields of the treatments are reported in Table III. An analysis of the results shows a significant difference between the yields. Treatments T1C2, T2C2, and T3C2 obtained cane yields ranging from 80,638 to 85,500 kg/ha, which were significantly lower than those of untreated plants. However, treatments T1C1, T2C1, and T3C1 produced intermediate yields ranging from 72,145 kg/ha to 76,875 kg/ha. These recorded yields are higher than the control (63,333 kg/ha).

Table 1. Effect of treatments on the number of stems per strain

Treatments	Treatment codes	Number of plants	
		At 3rd month	At fifth month
Zingiber officinale treatments	T1C2	23,75±3.5c	27,0±5,2a
	T1C1	35,25±5,5a	24,5±2,50a
	T2C2	33,50±12,2a	18,5±2,0b
	T2C1	35,75±7,6a	17,75±4,0b
	T3C2	34,50±12,4a	24,50±2,3a
	T3C1	26,50±6,95b	26,75±4,4a
Mineral oil	Banole	29,25±4,99b	25,75±3,7a
Control	(TE)	33,75±14,6a	21,5±3,10b

Means followed by the same letters in the same column and row are not significantly different at the 5% threshold according to the Newman-Keuls test.

Table 2. Number of stems per hectare according to treatments

Treatments	Codes	Average number of stems/ha
Zingiber officinale treatments	T1C2	132 386,3 ±3662,90a
	T1C1	134 934,0 ±3276,66a
	T2C2	93 267,0 ±2462,30b
	T2C1	133 644,0 ±8694,35a
	T3C2	101 136,0 ±4185,60ab
	T3C1	108 231,0 ±9905,33ab
Mineral oil	Banole	90 300,0±2090,04b
Control	(TE)	96 224,0±1782,51b

Means followed by the same letter in the same column and row are not significantly different at the 5% threshold according

to the Newman-Keuls test

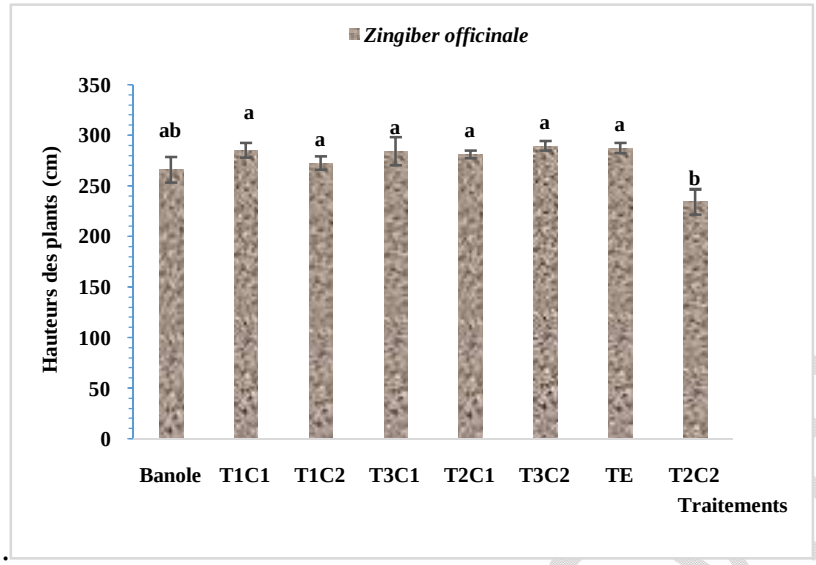

Figure 1. Effect of treatments on average plant height

3.2 Effects of treatments on phytosanitary parameters

3.2.1 Incidence of smut

The evolution of sugarcane smut incidence according to treatments is shown in Figure 2. The analysis of variance revealed a highly significant effect ($p \leqslant 0.05$) and the Newman-Keuls test allowed for the classification of the incidences into different groups. The incidence on the treated plants did not show a difference between the third and fifth months, but it did vary for the control.Thus, in the third month, the highest incidences of smut disease were observed in the control group (TE) and for mineral oil with respective values of 20.51% and 17.59%. Conversely, treatments T1C2 (8.67%) and T1C1 (8.95%) reduced the incidence. Intermediate incidences were recorded for T2C2, T2C1, T3C2 and T3C1 treatments, with respective incidences of 10.91%, 11.13%, 11.60% and 11.17%.In the 5th month, T1C2 treatment displayed a low incidence rate of 7.91%, while high incidence rates were observed in the control and mineral oil (Banole) groups with incidences of 19.79% and 17.42%, respectively. T1C1, T2C2, T2C1, T3C2, and T3C1 treatments had intermediate incidences varying between 9.78% and 11.44% (Figure 2).

Table 3. Sugarcane yields by treatment

Treatments	Codes	Cane yield (kg/ha)
Zingiber officinale treatments	T1C2	65 583,3 ± 2753b
	T1C1	82 388,9 ± 12893 a
	T2C2	74 222,2 ± 9446ab
	T2C1	80 638,9 ± 10808a
	T3C2	75 527,8 ± 18068ab
	T3C1	85 500 ± 11834a
Mineral oil	Banole	72 722,2 ± 10017ab

Control	(TE)	63 333,3 ± 1341b

Means followed by the same letters in the same column and row are not significantly different at the 5% threshold according to the Newman-Keuls test.

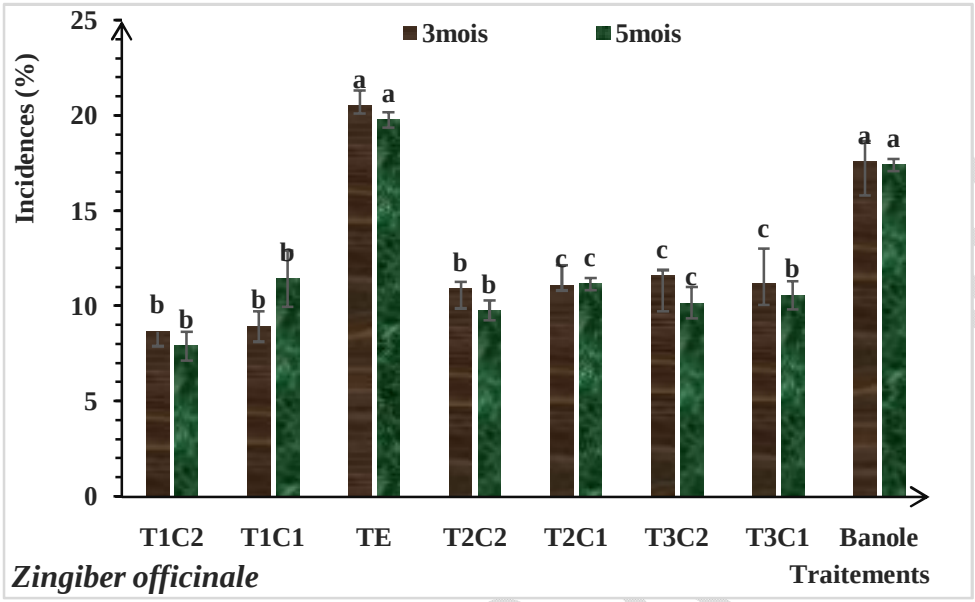

Figure 2. Effects on smut incidence trends

3.2.2 Effects of different essential oil treatments on the number of shoots/ha

The effect of treatments on the average number of shoots and stem gain is presented in Table IV. Statistical analysis revealed a difference in the number of shoots. The number of shoots was significantly higher in untreated plants (17,673 shoots/ha) and plants treated with mineral oil (13,319 shoots/ha).The treatments T1C2, T1C1, T2C1, and T3C2 recorded a low number of shoots oscillating between 8465 and 11701 shoots/ha, or a gain in shoots of between 5972.2 and 9208.3 shoots. On the other hand, treatments T2C2 and T3C1 had a shoot density of more than 10000 shoots/ha.

Table 4. Number of shoots/ha and gain in machinable stems according to treatments

Treatments	Codes	Number of shoots/ha	Stem gains/ha
*Zingiber officinale*treatments	T1C2	8 465,27±924,69d	9 208,3
	T1C1	9 770,83±1250,16d	7 902,7
	T2C2	11 701,38±1156,91c	5 972,2
	T2C1	9 805,55±1125,16d	7 868,05
	T3C2	9 562,5±1337,43d	8 111,1
	T3C1	10 263,88±1231,73c	7 409,72

Mineral oil	Banole	13 319,44±1516,53b	4 354,16
Control	(TE)	17 673,61±2164,7a	-

Means followed by the same letters in the same column and row are not significantly different at the 5% threshold according to the Newman-Keuls test.

3.3 Technological analysis

3.3.1 Effect of treatments on technological quality

The technological characteristics of richness in saccharine, purity, extractable sugar, and extractable sugar yield are presented in Table V. Significant differences were indicated by statistical analysis. The various treatments performed with Zingiber officinale essential oil improved the technological qualities. The saccharine richness achieved in treatments T2C1, T2C2, T3C1, and T3C2 in Poland registered Pol values ranging from 13.24% to 13.75% above that observed in untreated plants (12.93%).With regard to juice purity, no significant differences were observed between treatments. Purity values ranged from 88.50 to 90.08%.In terms of extractable sugar and sugar yield, treated plants were far superior to untreated plants. Treatments T2C1, T2C2, T3C1 and T3C2 recorded the highest proportions of extractable sugar and yields. Treatments T3C2, T3C1, T2C2 and T2C1 achieved yields of 8.15 t/ha, 7.24 t/ha, 7.59 t/ha and 7.32 t/ha respectively. However, yields were low for untreated plants (5.80 t/ha), mineral oil (6.87 t/ha) and T1C1 (6.42 t/ha).

Table 5. Technological quality as a function of treatments with *Zingiber officinale* essential oil

Treatments	Codes	Saccharin richness (Pol %)	Juice purity	Extractable sugar (SE%)	Extractable Sugar yield (TSE/ha)
*Zingiber officinale*treatments	T1C2	12,79b	88,66b	8,83b	5,80b
	T1C1	12,93b	88,50b	8,98b	6,42ab
	T2C2	13,75a	90,08b	9,78a	7,32a
	T2C1	13,24a	89,25b	9,25a	7,59a
	T3C2	13,52a	89,68b	9,46a	7,24a
	T3C1	13,47a	89,70b	9,42a	8,15a
Mineral oil	Banole	13,50a	89,29b	9,45a	6,872ab
Control	(TE)	12,93b	89,01a	8,93b	5,65b

Means followed by the same letters in the same column and row are not significantly different at the 5% threshold according to the Newman-Keuls test.

3.3.2 Group characterization of different treatments with *Zingiber officinale* essential oil

The growth parameters (tillage) and sugarcane yields (stalk gains and cane yield) are positively correlated with Factor 1 (Axis 1), which accounts for 64.39% of the total variance of treatments, with r = 0.98, 0.59, 0.62, and 0.17, respectively.While the phytosanitary parameters smut incidence and number of shoots are negatively correlated with factor 2 (axis 2), which accounts for 28.99% of total trial variance, with r = -0.93; -0.16 and -0.06.It is from these

correlations between variables and factors (1 and 2) that the dispersion of treatments in the factorial plane (Figure 3) is interpreted. The PCA scatter plot for the different *Zingiber officinale* treatments thus reveals three groups of varieties (Figure 3): Mineral oil (Banole) and control (TE) (group 1) are highly favorable to the development of smut. They induce high charcoal rates and high incidences. Group 2 comprises treatments T1C1, T2C2, T3C2 and T3C1. They are characterized by the best performance in terms of cane yield, growth parameters, tillering and cane stalk gain.They reduce whip number development and the incidence of the smut disease. Treatments T1C2 and T2C1 (group 3) demonstrate a positive impact on growth and development parameters with a significant reduction in the smut disease, but with a moderate cane yield (Figure 3).

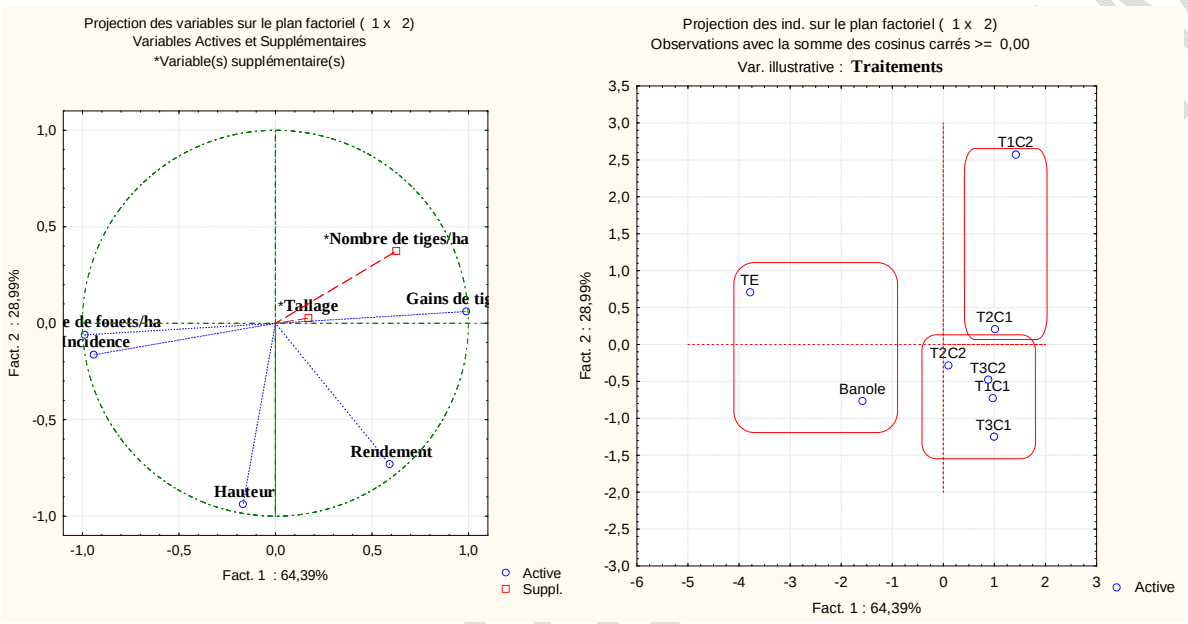

Figure 3. Treatment groups determined by principal component analysis for *Zingiber Officinale* treatment

3.4 Economic evaluation of treatments

The costs of phytosanitary treatments are recorded in Table VI. Regarding treatments with *Zingiber officinale* oil, the phytosanitary treatment costs were higher with treatments T3C2 and T3C1, costing 252,000 FCFA/ha and 192,000 FCFA/ha, respectively.On the other hand, phytosanitary treatment costs were lower for T1C1 and T2C1, at 117,000 FCFA/ha. Gross margin analysis was higher for treatments T2C1, T2C2, T3C1 and T3C2, ranging from 1,135,500 FCFA/ha to 1,623,000 FCFA/ha. Economic profitability was higher in treatments T2C2 (9.70) and T2C2 (7.98). Treatment T1C1, on the other hand, recorded a negative gross margin and financial profitability (-0.038).

Table 6 :The costs of phytosanitary treatments are recorded

Treatments	**CTP** (en FCFA)	Sugar yield(t/ha)	Gain in sugar content. (t/ha)	CVR (FCFA)	CTP (FCFA)	MB (FCFA)	r
T1C1	117 000	5,8	0,15	112 500	117 000	-4 500	-0,038
T1C2	162 000	6,42	0,77	577 500	162 000	415 500	2,56
T2C1	117 000	7,32	1,67	1 252 500	117 000	1 135 500	9,70

T2C2	162 000	7,59	1,94	1 455 000	162 000	1 293 000	7,98
T3C1	192 000	7,24	1,59	1 192 500	192 000	1 000 500	5,21
T3C2	252 000	8,15	2,5	1 875 000	252 000	1 623 000	6,44

Means followed by the same letters in the same column and row are not significantly different at the 5% threshold according to the Newman-Keuls test.

4. DISCUSSION

The sugarcane smut fungus infects sugarcane plants through buds or young germinating shoots and develops in association with the plant's lateral meristems as they grow [20]. Our study demonstrates that the application of the *Zingiber officinal*based fungicide effectively combats the smut disease.Our results have shown that the incidence of the disease was greatly reduced by all treatments, demonstrating that the ginger-based fungicide, applied via spraying, protected young sugar cane stems against soil infections. The results are inconsistent with those reported by [21], who found that the carboxin-based fungicide had little effect in controlling sugarcane smut when sprayed on young plants.The incidences did not show a significant variation between the 3rd and 5th month in treated plants. This also proves that the essential oil of *Zingiber officinale* used for substantial control of the charcoal disease exhibits systemic activity.These results support those obtained by [22], who reported the antifungal effects of this oil in vitro on *Sporisoriumscitamineum*. These findings are similar to those of [21], which demonstrated significant control of sugarcane smut through the application of the fungicide triadimefon to the soil at planting.Furthermore, several studies have confirmed the antimicrobial properties of this essential oil ([24]; [25]). The findings of [26] align with our own, demonstrating that the oil has antifungal properties and could be utilized in post-harvest treatments for mangoes.This activity would depend on chemical compounds that act in synergy to alter the permeability of membranes and denature the proteins of the pathogen [27]. The essential oil of *Zingiber officinale* is composed of arcurcumene (59%), β-myrcene (14%), 1,8-cineole (8%), citral (7.5%), and alpha-zingiberene (7.5%) [27]; [29], which represents the active ingredient in the natural fungicide that would exert a toxic effect on *Sporisoriumscitamineum*.Our studies have demonstrated a significant increase in disease incidence among untreated plants between the third and fifth months, thus supporting the notion that secondary disease propagation occurred after pruning. Furthermore, if the infection occurred between the second and fifth months, it also implies that the fungicides protected the plants for two to four months. Our results also indicate that the use of *Zingiber officinale* treatment has positive effects on plant height, tillering, and sugarcane yield. The responses to disease management coincide with the reported losses by the smut disease in susceptible varieties [30]. Additionally, the technological quality parameters of sugarcane such as purity, Brix, and extractable sugar content were not hindered by the

treatment. Our results indicate that the treatment not only acts as a protector, but also does not impact the quality of the sugar. The economic analysis results demonstrate that the treatments are economically feasible.Our results contradict those of [23], who demonstrated that pesticide treatments in sugarcane cultivation are not economically profitable. The essential oil of *Zingiber officinale* has fungicidal properties that are similar to those of the synthetic fungicide propiconazole [22]. This treatment for young shoots using Ginger officinale essential oil presents an alternative solution to chemical-based products for combating smut disease. However, these fungicides can cause skin allergies and are suspected of being carcinogenic [11].

5. CONCLUSION

The sugarcane smut is one of the most damaging fungal diseases worldwide. Applying a fungicide based on *Zingiber officinale* oil at a rate of 1500 ppm and 2500 ppm on young shoots, 15 days after harvest, reduced disease incidence.It has also promoted the growth and development of plants without compromising the technological quality of sugarcane. Additionally, the treatment is cost-effective and serves as an alternative to the use of chemicals in combating the black fungus disease.

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