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ORIGINAL

Use of cocoa mucilage (Theobroma cacao L.) for the control of weeds in african palm (Elaeis guineensis)

Uso del mucílago de cacao (Theobroma cacao L.) para el control de arvenses en palma africana (Elaeis guineensis)

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ABSTRACT

The use of cocoa mucilage to control weeds in African palm (Elaeis guineensis) was evaluated, given the need for sustainable alternatives for weed control. As an objective of the study, the effectiveness of different concentrations of mucilage (0 %, 60 %, 80 % and 100 %) on broad-leaf and narrow-leaf weeds was evaluated. This study was developed by directly applying cocoa mucilage to the experimental plots, evaluating different variables such as weed cover, mortality and biomass weight. The results showed significant differences in weed coverage before and after the application of the bioherbicide. The treatment with broad leaves reached a coverage of 62,37 %, while the treatment with narrow leaves had 50 % coverage. Regarding weed mortality, the treatment with 100 % mucilage and narrow leaf achieved a mortality of 99 %, while the treatment with 60 % mucilage and broad leaf had a mortality of 46 %. Biomass weight, the treatment with broad leaves recorded the highest initial weight of 606 g, but the treatment with 100 % mucilage and narrow leaves had the lowest weight of dead biomass, with only 73 g. In conclusion, treatment with 100 % mucilage and narrow leaf showed the best results in controlling weeds in African palm. This study highlights the potential of mucilage as a bioherbicide and its effectiveness in agriculture.

Keywords: Weeds; Bioherbicide; Biological Control; Mucilage; Palm.

RESUMEN

Se evaluó el uso del mucílago de cacao para controlar arvenses en palma africana (Elaeis guineensis), dada la necesidad de alternativas sostenibles para el control de malezas. Como objetivo de estudio se evaluó la efectividad de diferentes concentraciones de mucílago (0 %, 60 %, 80 % y 100 %) sobre arvenses de hoja ancha y hoja angosta. Este estudio se desarrolló aplicando de manera directa el mucílago de cacao sobre las parcelas experimentales, evaluando diferentes variables como la cobertura de arvenses, mortalidad y peso de la biomasa Los resultados mostraron diferencias significativas en la cobertura de arvenses antes y después de la aplicación del bioherbicida. El tratamiento con hoja ancha alcanzó una cobertura del 62,37 %, mientras que el tratamiento con hoja angosta tuvo un 50 % de cobertura. En cuanto a la mortalidad de los arvenses, el tratamiento con 100 % de mucílago y hoja angosta logró una mortalidad del 99 %, mientras que el tratamiento con 60 % de mucílago y hoja ancha tuvo una mortalidad del 46 %. El peso de biomasa, el tratamiento con hoja ancha registró el mayor peso inicial de 606 g, pero el tratamiento con 100 % de mucílago y hoja angosta tuvo el menor peso de biomasa muerta, con solo 73 g. En conclusión, el tratamiento con 100 % de mucílago y hoja angosta mostró los mejores resultados en el control de arvenses en palma africana. Este estudio destaca el potencial del mucílago como bioherbicida y su efectividad en la agricultura.

Palabras clave: Arvenses; Bioherbicida; Control Biológico; Mucílago; Palma.

INTRODUCTION

The cultivation of cocoa (Theobroma cacao L.) represents Ecuador's third most important agricultural export product, constituting a strategic pillar of the national agro-industrial sector.[1] According to the National Agricultural Census, this species is estimated to be cultivated on approximately 243059 hectares under monoculture systems and 191272 hectares associated with other agricultural species, totaling around 433978 hectares dedicated to its production.[2] This extensive cultivated area not only sustains an export-based economy but also generates a wide range of products, by-products, and agro-industrial waste, the integral use of which constitutes a key opportunity for sustainable development and technological innovation in the cocoa value chain.[3]

Currently, by-products derived from cocoa processing, particularly mucilage, have attracted increasing interest for their potential in developing compounds with agroecological applications, such as bioherbicides, bio fungicides, and even bioinsecticides.[4] This secondary biomass, the cocoa pulp, corresponds to a viscous and translucent matrix surrounding the seeds inside Theobroma cacao L's fruit. Each fruit contains between 30 and 50 seeds, whose number, shape, and size can vary.[5]

These seeds, which are ellipsoidal and flattened in morphology, with lengths ranging from 2 to 4 cm, are enveloped by a whitish, sugary coating composed predominantly of parenchymal tissue. The mucilaginous pulp consists of spongy parenchymatous cells with a high concentration of reducing sugars, pentoses, citric acid, and essential minerals, making it a valuable source for agro-industrial valorization.[6]

In African palm(Elaeis guineensis) production systems, weeds represent a significant phytosanitary risk factor since these adventitious species can act as alternative hosts for various pests and diseases. A relevant example is lethal wilt, a pathology whose etiology is still debated but potentially attributed to a phytoplasma spread by insects of the order Hemiptera that complete their biological cycle in multiple species of weeds present in plantations.[7] Given this risk, it is imperative to implement effective weed management and control strategies in the crop environment.

In particular, maintaining the 'saucer,' a circular zone of 2,5 to 3 meters radius around the stipe, is a widely adopted practice. This intervention aims to minimize interspecific competition for essential resources such as water, light, and nutrients and to optimize agricultural tasks related to bunch picking, irrigation, fertilization, loose fruit collection, and preventive sanitary actions.[8]

Considering the growing concern about the intensive and indiscriminate use of agrochemical inputs, a common practice in more than 85 % of producers in the agricultural sector, Vera mentions in 2023,[9] and the urgent need to mitigate the environmental impacts, especially on soil and water resources, it is a priority to promote sustainable alternatives within the production systems. This need is intensified by the scarce implementation of biomass recycling practices within agricultural production units.[6]

In this context, the development and implementation of bioherbicides are emerging as a promising strategy for weed management. These biological solutions not only contribute to reducing dependence on synthetic herbicides but could also improve the productive efficiency of the agroecosystem and promote a more balanced and regenerative management of natural resources.[10]

Given the above, the purpose of this study was based on using a by-product of agro-industrial origin, such as cocoa (Theobroma cacao L.) mucilage in different concentrations, to control weeds in broad and narrow leaves in a crop of African palm (Elaeis guineensis), promoting agroecological practices and thus encouraging the reduction of the use of chemical inputs.[11]

METHOD

Type of Study

The research corresponds to a quantitative experimental field study in which different concentrations of cocoa mucilage were evaluated under specific agroecological conditions to control broadleaf and narrow-leaf weeds.

Location

The experimental study was conducted at the 'Sarafica' farm, owned by Mr. Francisco Tobar, located in the 24 de Mayo sector, jurisdiction of the canton of Quevedo, province of Los Ríos, Ecuador. The production unit is 72 meters above sea level, with geographical coordinates of 1°02'01.9'south latitude and 79°30'48.1' west longitude. These conditions correspond to a low-altitude zone with a humid tropical climate, characteristics typical of this high-yielding agricultural region.

Table 1. Agro-climatic conditions in the canton of Quevedo

Agro-climatic data	Averages
Temperature °C	24
Average relative humidity (%)	90
Heliophany daylight hours/year	900
Precipitation mm/year	2298,2
Topography of the terrain	Slightly regular

Universe and sample

The universe studied consisted of the production unit's weed population. The experimental sample was determined by delimited plots, to which eight different treatments were applied, each with three replications.

Experimental design

The experiment was structured under a completely randomized design (CRD) with a 4 × 2 factorial arrangement, corresponding to two factors: A (percentage of cocoa mucilage applied) and B (type of weeds). Factor A included four concentration levels (0 %, 50 %, 75 %, and 100 % mucilage), while factor B included two groups of weeds, broad-leaved and narrow-leaved, giving eight experimental treatments. Each treatment was replicated three times. The data obtained were statistically analyzed by calculating the arithmetic mean and corresponding standard deviation (SD). Before the application of the analysis of variance (ANOVA), the normality of the data was verified using the Kolmogorov-Smirnov test, establishing a significance level of $p < 0,05$.

Variables evaluated

The following variables were evaluated for this research:

Visual control of weed cover: using observation, the percentage of the area covered by weeds in each plot before the first and second applications was estimated. The scale proposed by Alam and cited in Hipo's research[12] was used (table 2).

Table 2. Scale for assessing weed cover

Scale	Designation
0-20	Nude
21-40	Slightly covered
41-60	Moderately covered
61-80	Highly covered
81-100	Fully covered
Source: [12]	

The evaluation of effect of the treatment on weed mortality was evaluated by applying a severity scale originally proposed by Alam, cited in the study by Méndez[13] (see table 3). This methodology allowed the degree of control exerted by the different treatments to be quantified and standardized, facilitating comparative interpretation between weed species and the levels of mucilage concentration applied.

Table 3. Scale for assessing weed mortality		
Index	**Level of control (%)**	**Description of control**
0	0-40	None to poor
1	41-60	Fair
2	61-70	Sufficient
3	71-80	Good
4	81-90	Very good
5	91-100	Excellent
Source: (13)		

Weight of green biomass of weeds: At the end of the trial, we removed the weeds present in each of the plots where the different treatments were applied to determine the weight of the remaining green biomass.[12]

Ethical considerations
This research did not involve humans or animals as a unit of study, so it was not necessary to submit it to an ethics committee. However, the principles of biosafety, responsible waste management, and no impact on the environment or any of the crops were complied with.

RESULTS
Average weed cover
In Table 4, the weed cover assessed 15 days after the first cleaning showed average values ranging from 43,67 % to 62,67 %. Treatment T1 (60 % mucilage + broadleaf) had the highest coverage (62,67 %), while treatment T4 (80 % mucilage + narrowleaf) had the lowest coverage (43,67 %). However, when evaluating the variable 15 days after the second application, a significant inversion in the results was observed: the control treatment (T01) reached the highest coverage, with an average of 70,33 %, in contrast to treatment T6 (100 % mucilage + narrow leaf), which showed a minimum residual coverage of 2,33 %, indicating an effective control of the weed population under these conditions.

Table 4. Percentage of cover (%) 15 days - 30 days

Treatments	Percentage of coverage 15 days		Percentage of coverage 30 days	
T01	61,33	a	70,33	a
T02	46,67	b	58,00	b
T1	62,67	a	53,00	b
T2	50,00	b	39,00	c
T3	61,67	a	39,00	c
T4	43,67	b	23,67	d
T5	61,33	a	15,00	e
T6	44,67	b	2,33	f
Media	54,00		37,54	
CV (%)	4,40		4,64	
Standard error	5,64		3,03	

Mortality of weeds
Table 5 shows that treatment T6 (100 % mucilage + narrow leaf) showed the highest efficacy, with 93 % mortality 15 days after the first application, which increased to 99 % after the second application. In contrast, treatment T1 (60 % mucilage + broadleaf) showed the lowest effectiveness, with mortality levels of 39,67 % and 46 % at 15 days after the first and second application, respectively. These results confirm the existence of significant differences both between mucilage concentration levels (factor A: 0 %, 60 %, 80 %, and 100 %) and between the morphological types of weeds evaluated (factor B: broad-leaved vs. narrow-leaved), underlining the differential interaction in the biological response of the adventitious species to the treatments applied.

Table 5. Average mortality at 15 days - 30 days

Treatments	Mortality after 15 days		Mortality at 30 days	
T01	0,00	g	0,00 g	g
T02	0,00	g	0,00 g	g
T1	39,67	f	46,00 f	f
T2	55,33	e	58,33 e	e
T3	71,67	d	79,00 d	d
T4	82,67	b	89,67 b	b
T5	79,67	c	86,67 c	c
T6	93,00	a	99,00 a	a
Media	52,75		57,33	
CV (%)	1,93		1,47	
Standard error	1,04		0,71	

Weight of biomass in weeds

The results presented in table 6 showed highly significant differences (P≤ 0,05 value) between the treatments. Therefore, it was demonstrated that treatment T5 obtained the highest green broadleaf biomass with a weight of 606 g after cleaning. The lowest of T02 was 324 g. Consequently, treatment T01 showed the highest weight, 572,33 g, and the lowest weight was of treatment T6, with 73,00 g of dead biomass after the second application, which indicates that there are significant differences between factor A (mucilage 0, 60, 80 and 100 %) and factor B (broadleaf and narrow-leaf vines) evaluated in this research.

Table 6. Weight of initial and final biomass

Treatments	Weight (g) Initial biomass		Weight (g) Final biomass	
T01	539,00	d	572,33	a
T02	324,00	g	363,33	c
T1	564,33	c	479,67	b
T2	332,67	g	215,67	e
T3	594. 67	b	327,67	d
T4	363,67	f	121,00	f
T5	606,00	a	199,67	e
T6	397,67	e	73,00	g
Media	465,25		290,29	
CV (%)	0,69		2,63	
Standard error	10,31		58,40	

DISCUSSION

The results show that cocoa mucilage demonstrates excellent efficacy as a bioherbicidal agent in field situations, particularly when applied at higher concentrations (80 % and 100 %) and applied sequentially. Within 15 days after the second application, treatment T6 reduced the plant cover to just 2,33 %, which allowed a mortality rate of 99 % to be achieved, which showed outstanding control.

In contrast to the results obtained in the present investigation, Aguilera[14] reported a maximum weed cover of 60 % and a minimum of 18 %. Perez[15] reported even higher values, with a cover range between 69,33 % and 48,00 %. These values generally exceed those observed in this study, where 15 days after cleaning, a maximum cover of 62,67 % (treatment T1) and a minimum of 43,67 % (treatment T4) was recorded. However, after the second application, the control treatment reached up to 70,33 % coverage. In comparison, the T6 treatment (100 % mucilage + narrow-leaved weeds) reduced the coverage drastically to only 2,33 %, showing a higher efficacy in biological control.

Discrepancies between the studies can be attributed to methodological differences: Aguilera[14] used a combination of glufosinate with cocoa mucilage in a single application, whereas in the present trial, different concentrations of purely natural mucilage were evaluated and applied twice. This strategy may have enhanced mucilage's progressive and sustained herbicidal effect, particularly on narrow-leaved weeds.

According to Plúas[16], in the application T4 glyphosate + mucilage (2 liters + 1 liter), he obtained plant mortality (weeds) of 92 %, and when using T1 glyphosate (1 ½ liter), 75 % mortality was recorded. Macias[17] presented in his research that the application of T5 with a mucilage fermentation time of 5 years obtained mortality of the plants (weeds) of 99,5 %, and when using T1 with a mucilage fermentation time of 1 day, 58,33 % of mortality was registered.

The results of the present investigation show that the T6 treatment (100 % mucilage + narrow-leaved weeds) achieved 99 % mortality 15 days after the second application. The T1 treatment (60 % mucilage + broad-leaved weeds) reported an average mortality of 46 % in the same period. These values differ significantly from those reported by Plúas[16], who used single concentrations of mucilage without varying the dosage levels or applying a sequential treatment scheme. In contrast, in this study, four concentrations (0 %, 60 %, 80 %, and 100 %) were evaluated with a regimen of two applications at 15-day intervals, which may have directly influenced the differential efficacy observed.

There are also discrepancies with the findings of Macías[17], who reported higher mortality rates, possibly due to the use of mucilage with a longer fermentation time (five years), which may have increased the concentration and stability of bioactive compounds responsible for the herbicidal action. In contrast, the mucilage used in the present study was subjected to a fermentation process of only 15 days. Despite this, the results were highly encouraging, with comparable levels of efficacy in some treatments, suggesting that even short fermentation periods can generate functional extracts with bioherbicidal potential, mainly if used at high concentrations and with repeated applications.

The study by Chu[18], which evaluated the effect of vinegar made from apple tree branches on broadleaf weeds grown in 0,10 m × 0,10 m pots, reported a maximum green biomass weight of 2,5 g under untreated conditions (75 % survival), and a minimum value of 0,5 g after vinegar application, reaching 95 % mortality. Although these results show an effective response to the treatment, the biomass magnitudes evaluated were substantially lower than those recorded in the present study, mainly due to the difference in experimental scale.

In this investigation, the control treatment (T01) reached a maximum dead biomass weight of 572,33 g. The T6 treatment (100 % mucilage + narrow-leaved weeds) presented a minimum weight of 73,00 g 15 days after the second application. It should be noted that these values were obtained in larger experimental plots (2 m × 2 m), which provides a more representative basis for evaluating the impact in the field. This methodological difference highlights the effectiveness of cocoa mucilage as a bioherbicide under larger-scale conditions, with a significant capacity to reduce weed biomass progressively and sustainably.

The cumulative action observed after two applications suggests that the mucilage acts progressively, possibly thanks to phenolic compounds, organic acids, or fermentative microorganisms present in the extract, as indicated by Delgado[19], who analyzed the chemical composition of cocoa residues.

CONCLUSION

The present study made it possible to quantify the initial coverage of weeds before applying cocoa mucilage-based bioherbicide treatments, with a high incidence of broad-leaved species and a moderate coverage of narrow-leaved species. This initial distribution revealed differences in the response of the biotreatments, showing variability in efficacy according to the morphological type of weeds.

The experimental results showed that the T6 treatment (100 % mucilage + narrow-leaved weeds) was the most effective in inducing mortality, followed by T4 (80 % mucilage + narrow-leaved weeds). This confirms the phytotoxic potential of cocoa mucilage as a natural bioherbicide input. This differential efficacy highlights its usefulness in integrated weed management programs in African palm production systems, especially in the control of graminoid species.

Likewise, the evaluation of the weight of green biomass at the end of the trial made it possible to assess the impact of the treatments on the vegetative growth of the adventitious species. Although differences were observed between treatments in terms of initial and final biomass weight, a significant reduction was observed in treatment T6, which supports its effectiveness in suppressing the development of narrow-leaved weeds. These findings reinforce the value of cocoa mucilage as a promising agroecological alternative to replace synthetic herbicides partially.

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