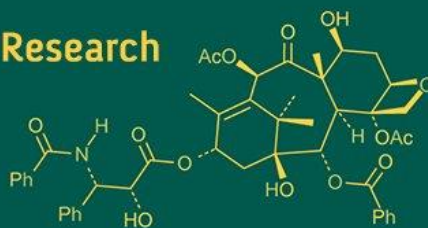
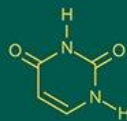
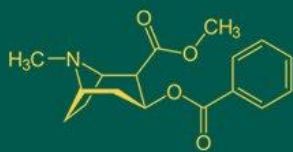


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Effect of different pollination methods and organic attractants on yield-attributing traits in Cocoa (*Theobroma cacao* L.)

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Abstract

The present investigation was carried out during 2024-25 in a farmer's orchard at Chikkala village, East Godavari district, Andhra Pradesh, to evaluate the effectiveness of different pollination techniques on yield-attributing traits in cocoa. The experiment followed a factorial randomized block design (FRBD) with three replications, involving six pollination methods namely natural pollination (P1), single hand pollination with fresh flowers (P2), double hand pollination with fresh flowers (P3), pollinator attraction using banana pseudostem (P4), cocoa pod shells (P5), and fermented *Mahua longifolia* seed cake with jaggery (P6). These treatments were evaluated across two cocoa varieties viz., Trinitario clone (V1) and Forastero clone (V2), resulting in 12 treatment combinations. The results revealed that pollination methods had a significant influence on key yield parameters, including pod set percentage, pod retention percentage, and number of pods per tree. In contrast, varietal differences were largely non-significant.

Keywords: Pollinator attractants, Hand pollination, Banana pseudostem, Mahua cake organic attractants

Introduction

Cocoa (*Theobroma cacao* L.), a major perennial crop cultivated globally for chocolate production, is grown in India over an area of 1,03,376 hectares, yielding 27,072 tons of dry beans with a productivity of 262 kg/ha. This places India 15th in global cocoa production—well behind West African countries such as Ivory Coast, Ghana, Nigeria, and Cameroon (DCCD, 2021). The relatively low productivity in India is primarily attributed to poor and inconsistent pollination.

Pollination in cocoa is predominantly carried out by midges (Diptera: Ceratopogonidae), whose population density significantly influences natural pollination success (Adjaloo *et al.*, 2013) [2]. Studies have shown that hand pollination markedly improves fruit set, pod development, and seed number (Adjaloo, 2012) [1], with a strong positive correlation between manual pollination per flower/day and overall yield (Sundararaju *et al.*, 2011) [12].

Ecological management strategies also contribute to pollination efficiency. Discarded cocoa pods, for example, serve as breeding sites for pollinating midges (Bridgemohan *et al.*, 2017) [5]. Organic substrates such as cocoa pod husks and banana pseudostem extracts have been shown to enhance midge populations, with banana extracts supporting the highest midge densities (Young *et al.*, 1986) [15]. Peak pollination activity has been observed around the eighth week following the application of such substrates (Adjaloo, 2012) [1]. Given this context, the present study was undertaken to evaluate the effectiveness of various pollination methods and organic attractants on yield and pod quality traits in cocoa.

Materials and Methods

The experiment was carried out during 2024-25 in a farmer's orchard at Chikkala village, East Godavari district, Andhra Pradesh, following a factorial randomized block design (FRBD) with three replications. Six pollination methods namely natural pollination (P1), single hand pollination with fresh flowers (P2), double hand pollination with fresh flowers (P3), pollinator attraction using banana pseudostem (P4), cocoa pod shells (P5), and

fermented *Mahua longifolia* seed cake with jaggery (P6) were tested across two cocoa varieties, Trinitario clone (V2) and Forastero clone (V1), producing 12 treatment combinations.

Each treatment was replicated three times, with five trees per replication, totaling 15 trees per treatment. Natural pollination (P1) was conducted under open field conditions without any intervention. In single hand pollination (P2), anthers were manually rubbed onto the stigma at anthesis, following the methods described by Madhu (1984)^[11] and Aneja *et al.* (1992)^[3]. Double hand pollination (P3) involved applying anthers from two different flowers to a single stigma to increase the pollen load.

The pollinator attractant treatments included the application of decomposing banana pseudostem (P4), cocoa pod shells spread around the base of trees (P5), and a fermented mixture of *Mahua longifolia* seed cake and jaggery (P6). For the latter, 2 kg of *Mahua longifolia* seed cake was mixed with 1 kg of jaggery in 20 liters of water and allowed to ferment for four days. Subsequently, 5 liters of this fermented solution was applied around each tree to attract pollinators through its strong volatile emissions.

This systematic experimental layout enabled a comprehensive evaluation of the effectiveness of different pollination techniques and attractants on pod set and yield related traits in two cocoa varieties viz., Trinitario and Forastero clones. Data were collected from five selected trees per treatment in each replication, and the mean values were used for statistical analysis.

Results and Discussion

Number of Flowering Cushions

No significant differences were observed between the two varieties or among the pollination methods regarding the number of flowers produced on both the main trunk and fan branches prior to the imposing the treatments, indicating comparable cocoa trees were selected for the application of treatments (Table 1 & 2).

Number of Pods per Cushion

The number of pods per cushion differed significantly across pollination treatments and the data is presented in Table 3. The highest number of pods (2.37) were recorded under fermented *Mahua longifolia* seed cake + jaggery (P6), followed by cocoa pod shells (2.11), which was statistically on par with banana pseudostem (2.05). Double hand pollination (P3) recorded 1.59 pods per cushion, while single hand (1.33) and natural pollination (1.27) produced the lowest pods per cushion. Varietal and pollination methods interaction effects ($V \times P$) were non-significant, indicating consistent response across both Trinitario and Forastero clones. These findings highlight the efficacy of pollinator attractants in enhancing fruit set, possibly due to increased pollinator activity, as compared to manual or natural pollination.

Days Taken to Pod Set

Days to pod set varied significantly among pollination methods, ranging from 4.22 days under natural pollination (P1) to 6.00 days in hand double pollination (P3) (Table 4). Treatments P2 (5.33 days) and P6 (4.83 days) were

statistically on par and intermediate. Among varieties, Trinitario clones took slightly longer (5.20 days) than Forastero clones (4.70 days), suggesting a minor varietal influence. However, the variety $\times$ pollination method interaction remained non-significant.

Pod Set Percentage

Pod set percentage showed significant variation across treatments. Results are summarized in Table 5. The highest pod set was recorded under hand single pollination (P2: 20.22%), followed closely by the fermented *Mahua* + jaggery treatment (P6: 18.50%), whereas natural pollination (P1) recorded the lowest pod set (10.48%). These results reinforce the role of direct pollen application in improving fertilization efficiency. However, attractant-based treatments like fermented *Mahua* + jaggery treatment (P6) demonstrated comparable performance by enhancing natural pollinator visitation (Toledo *et al.*, 2023; Forbes *et al.*, 2019)^[13, 9].

Pod Retention Percentage

Significant differences were observed in pod retention among treatments (Table 6). The highest retention was recorded under fermented *Mahua* + jaggery treatment (P6: 97.22%), whereas the lowest was observed in hand double pollination (P3: 62.72%). Although P2 enhanced pod set percentage, retention was lower, possibly due to mechanical damage caused during pollination, which may have disrupted delicate floral tissues, impaired fertilization, and triggered pod abscission through ethylene production. These findings are consistent with earlier reports by Falque *et al.* (1995)^[8], Daymond *et al.* (2002)^[7], Bos *et al.* (2007)^[4], Frimpong-Anin *et al.* (2014)^[10], and Yamada *et al.* (2020)^[14].

Days from Pod Set to Maturity

Pod development duration ranged from 149.45 days under natural pollination (P1) to 156.83 days in P5 (Table 7). Variety Forastero clone (V2) took longer time to reach maturity (162.11 days) than Trinitario (V1: 144.82 days). However, differences among pollination methods were statistically non-significant, suggesting that pod maturity is more genotype-dependent than pollination-method dependent.

Number of Pods per Tree

Pollination methods had a significant effect on the number of pods per tree. The data is presented in Table 8. The highest mean was recorded under fermented *Mahua* + jaggery treatment (P6: 14.13 pods/tree), indicating that pollinator attraction using fermented *Mahua* seed cake and jaggery substantially enhanced reproductive success. Hand single pollination (P2: 12.88 pods/tree) also performed well and was statistically on par with banana pseudostem treatment (P4: 10.61). Natural pollination (P1) produced the lowest number of pods per tree (8.42).

These results clearly suggest that natural pollination alone is insufficient for achieving optimal yield levels, and that enhancing pollinator activity through organic attractants or manual pollination can significantly improve productivity.

Table 1: Effect of method of pollination and variety on Number of flowering cushions on main trunk

		Method of Pollinations						Means of variety
		P1	P2	P3	P4	P5	P6	
Variety	V1	13.07	13.50	14.73	14.20	14.87	15.07	14.24
	V2	13.17	14.43	15.05	13.67	14.67	13.03	14.00
Means of Method of Pollinations		13.12	13.97	14.89	13.93	14.77	14.05	
		SEm ±						CD @ 0.05
V		0.285						NS*
P		0.493						NS*
V x P		0.697						NS*

Table 2: Effect of method of pollination and variety on Number of flowering cushions on fan branches

		Method of Pollinations						Means of Variety
		P1	P2	P3	P4	P5	P6	
Variety	V1	109.43	109.78	113.78	105.33	100.44	102.67	106.91
	V2	109.44	107.00	112.33	113.56	111.89	100.67	109.15
Means of Method of Pollinations		109.44	108.39	113.06	109.45	106.17	101.67	
		SEm ±						CD @ 0.05
V		2.782						NS*
P		4.818						NS*
Vx P		6.814						NS*

Table 3: Effect of method of pollination and variety on Number of pods per cushion

		Method of Pollinations						Means of Variety
		P1	P2	P3	P4	P5	P6	
Variety	V1	1.20(3.42*)	1.26(4.64*)	1.52(3.90*)	1.97(3.97*)	2.04(3.33*)	2.30(4.66*)	1.71(3.98*)
	V2	1.34(3.35*)	1.41(4.56*)	1.67(3.41*)	2.12(3.72*)	2.19(3.56*)	2.44(4.63*)	1.86(3.87*)
Means of Method of Pollinations		1.27(3.38*)	1.33(4.60*)	1.59(3.66*)	2.05(3.84*)	2.11(3.44*)	2.37(3.87*)	
		Sem ±						CD @ 0.05
V		0.048*						NS*
P		0.083*						0.244
Vx P		0.117*						NS*

Table 4: Effect of method of pollination and variety on Days taken to pod set

		Method of Pollinations						Means of Variety
		P1	P2	P3	P4	P5	P6	
Variety	V1	4.33	5.55	6.56	4.56	5.22	5.00	5.20
	V2	4.11	5.11	5.45	4.22	4.67	4.67	4.70
Means of Method of Pollinations		4.22	5.33	6.00	4.39	4.95	4.83	
		Sem ±						CD @ 0.05
V		0.139						0.406
P		0.240						0.704
Vx P		0.339						NS*

Table 5: Effect of method of pollination and variety on Pod set percentage

		Method of Pollinations						Means of Variety
		P1	P2	P3	P4	P5	P6	
Variety	V1	10.74 (3.42*)	20.56 (4.64*)	14.33 (3.90*)	14.78 (3.97*)	10.11 (3.33*)	18.44 (4.40*)	14.83 (3.93*)
	V2	10.22 (3.34*)	19.89 (4.56*)	10.67 (3.41*)	12.89 (3.72*)	11.71 (3.56*)	18.55 (4.42*)	13.99 (3.83*)
Means of Method of Pollinations		10.48 (3.38*)	20.22 (4.60*)	12.50 (3.66*)	13.84 (3.84*)	10.91 (3.44*)	18.50 (4.41*)	
		SEm ±						CD @ 0.05
V		0.044*						NS*
P		0.077*						0.277*
VxP		0.109*						NS*

Table 6: Effect of method of pollination and variety on Pod retention percentage

		Method of Pollinations						Means of Variety
		P1	P2	P3	P4	P5	P6	
Variety	V1	65.20 (57.6*)	69.00 (56.18*)	69.44 (56.47*)	94.33 (76.47*)	95.89 (78.57*)	97.78 (84.59*)	81.94 (68.29*)
	V2	74.78 (70.30*)	68.67 (55.95*)	56.00 (48.43*)	91.88 (74.47*)	89.44 (72.49*)	96.67 (79.99*)	79.57 (66.94*)
Means of Method of Pollinations		69.99 (63.96*)	68.84 (56.07*)	62.72 (52.45*)	93.11 (75.42*)	92.67 (75.48*)	97.22 (82.29*)	
		SEm ±						CD @ 0.05
V		0.924*						NS*
P		1.601*						4.725*
Vx P		2.264*						6.683*

Table 7: Effect of method of pollination and variety on Days taken topod set to maturity

		Method of Pollinations						Means of Variety
		P1	P2	P3	P4	P5	P6	
Variety	V1	143.78	142.33	143.34	149.89	148.78	140.78	144.82
	V2	155.11	164.11	165.33	160.56	164.89	162.67	162.11
Means of Method of Pollinations		149.45	153.22	154.34	155.22	156.83	151.72	
		SEm ±						CD @ 0.05
V		1.821						5.341
F		3.154						NS*
VxP		4.461						NS*

Table 8: Effect of method of pollination and variety on Number of pods per tree

		Method of Pollinations						Means of Variety
		P1	P2	P3	P4	P5	P6	
Variety	V1	8.88	13.42	9.33	9.89	9.89	13.96	10.90
	V2	7.97	12.33	8.73	11.32	9.67	14.30	10.72
Means of Method of Pollinations		8.42	12.88	9.03	10.61	9.78	14.13	
		SEm ±						CD @ 0.05
V		0.236						NS*
P		0.409						1.199
Vx P		0.578						NS*

Conclusion

Pollination method significantly influenced cocoa yield performance. Among the treatments, the use of fermented *Mahua longifolia* seed cake with jaggery water (P6) emerged as the most effective in enhancing pod retention and overall productivity. Hand single pollination (P2) resulted in the highest pod set percentage, demonstrating the efficiency of direct pollen application. However, manual pollination methods may inadvertently cause mechanical injury to the floral structures, potentially leading to reduced pod retention due to floral damage and subsequent abscission. In contrast, attractant-based approaches such as P6 offer a more sustainable and less intrusive alternative by stimulating natural pollinator activity and improving fertilization efficiency. These findings suggest that organic pollinator attractants represent a promising strategy for enhancing cocoa yields under field conditions.

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