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Impact of the Implementation of the Fruit Fly Control Project on the Household Income of Mango Producers in Côte d'Ivoire

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ABSTRACT

Although Côte d'Ivoire's mango sector is a leading exporter in Africa, it faces significant challenges due to fruit flies, which cause substantial economic losses. This study assesses the impact of the Fruit Fly Control Project (PLMF/ECOWAS) on the incomes of mango-producing households in northern Côte d'Ivoire. The research surveyed 378 households across the regions of Korhogo, Sinématiali, and Ferkessédougou. The average orchard size was 6.06 hectares. In 2019, households employing control measures marketed an average of 10.03 tons of mangoes, compared to less than 3 tons among those not implementing any control strategy. Average yields rose from 1.15 t/ha in 2015 to 1.56 t/ha in 2019, representing an increase of 413 kg/ha (approximately 20 crates per hectare). Producers utilizing the ternary method—combining sanitation, sexual attractants, and food baits, achieved an average production of 21.8 tons. However, this method incurred the highest production costs, at 127,838 FCFA/ha, and yielded an average net profit of 57,193 FCFA/ha, which is lower than that achieved through sanitation alone (183,719 FCFA/ha). The mean input cost was 54,724 FCFA/ha, with considerable variation: 45,310 FCFA/ha for sanitation and 80,250 FCFA/ha for the ternary method. The average gross margin stood at 100,317 FCFA/ha, peaking at 191,632 FCFA/ha for sanitation. The mean

regional net profit was 94,782 FCFA/ha, but this figure turned negative (−82,805 FCFA/ha) for less efficient producers. Approximately 77.6% of producers were found to be economically efficient, with an average yield of 1.79 t/ha and an average input cost of 45,476 FCFA/ha. The average daily labor value was 5086 FCFA, though this dropped to 757 FCFA among those using the ternary method. The sustainability of the project remains uncertain in the absence of subsidies, primarily due to high input costs, the technical complexity of treatments, and the lack of certain equipment. The study therefore recommends prioritizing simpler or binary control methods and maintaining technical support and subsidies to ensure the sustainability of the project's achievements.

1. INTRODUCTION

As the flagship of fruit diversification in Côte d'Ivoire, mango cultivation has become a significant driver of the country's economic development. Mango is currently the second most exported fruit from Côte d'Ivoire, following bananas and ahead of pineapples. Collectively, these three crops contribute between 3% and 4% to the national Gross Domestic Product (GDP) and account for 8% to 10% of the agricultural GDP. Over 95% of the mangoes exported are destined for the European market.

Export volumes have shown a steady upward trend in recent years, increasing from 20,475 tons in 2014 to 33,243 tons in 2018, and exceeding 34,000 tons in 2023. This growth generates an annual income of nearly 7 billion FCFA for more than 7000 rural producers and supports the livelihoods of over 100,000 individuals [1].

In Côte d'Ivoire, as in the wider West African region, the mango sector constitutes a major source of agricultural income, rural employment, and foreign exchange earnings. Côte d'Ivoire is notably the leading African exporter of mangoes to the European Union. Nevertheless, recurrent infestations by fruit flies, particularly Bactrocera dorsalis, pose a significant threat to the sanitary quality of exported mangoes, resulting in post-harvest losses, border interceptions, and unstable incomes [2].

To address this challenge, ECOWAS, UEMOA, and their technical partners launched the Fruit Fly Control Project (PLMF) in 2015. This initiative introduced integrated pest management strategies, including the use of sexual attractants, food baits, and improved orchard sanitation. The aim of this study is to assess the impact of these interventions on the economic performance of mango producers in northern Côte d'Ivoire.

The overarching aim of the project is to enhance the incomes of producers, with a particular focus on small-scale farmers, thereby contributing to food security in the sub-region and to poverty alleviation. More specifically, the project aims to 1) eliminate barriers to export and effectively control losses caused by fruit fly infestations, and 2) increase the quantity of marketable fruits that are free from infestations.

Since 2015, considerable efforts have been undertaken to mitigate the damage caused by fruit flies. These efforts include, among others, the identification and equipping of regional and national surveillance points and orchards for the purpose of issuing alerts; the training of producers in various pest management techniques; the dissemination of awareness-raising radio broadcasts during the campaign period; the training of field-side sorting staff (harvesters); the training of personnel at packing stations; and the communication and sensitization of stakeholders regarding new EU regulations. Collectively, these measures have served to strengthen both the quality and quantity of mangoes produced and exported, thereby increasing the level of activity across all actors in the value chain.

Accordingly, this study was launched to provide comprehensive information on the project's performance since its inception, with particular emphasis on its impact on the incomes of producer households in production areas.

2. METHODOLOGY

Two methodological approaches were adopted: a qualitative approach, which involved conducting interviews with key actors in the mango value chain (including exporters and producers), as well as resource persons (such as local MINADER officials, ANADER agents, and researchers); and a quantitative approach, which entailed administering a structured questionnaire to a representative sample of mango producers within the project area.

The quantitative methodology was grounded in the construction of a mango production budget as described by [3] [4], based on data collected through farm-level surveys. This approach was favored over an impact assessment utilizing a control group, given that agricultural inputs have been subsidized and distributed to producers since the 2015 production season. Consequently, nearly all mango producers currently employ one or more products for fruit fly control. This situation, therefore, does not allow for the credible definition of a meaningful control group (counterfactual).

Within the framework of crop budget development, the following indicators, measured per hectare, are particularly relevant for assessing the impact of improved fruit fly control methods on producers' incomes:

- Mango export yield per hectare
- Gross margin
- Net profit, and
- Valuation of labor per day in FCFA/day

These indicators were evaluated based on the various combinations of fruit fly control strategies implemented by the producers. Furthermore, the efficiency analysis of the producers offers valuable insights into the study's findings.

Statistical analyses were performed using a stratified random sample of 378 mango-producing households. The regions of Korhogo, Sinématiali, and Ferké served as the three strata. Data analysis was conducted using the econometric software Stata, version 14.

Sample Size Determination

In a stratified sampling design, the sample size is determined separately for each stratum, and the total sample size is the sum of the sample sizes across all strata. The calculation of the sample size for each stratum was performed using the formula proposed by [5].

$$N = [Nz^2p(1 - p)]/[d^2(N - 1) + z^2p(1 - p)], \text{ where:}$$

N: the population size within each stratum;

Z: the confidence interval;

P: the proportion of the target population within the overall population;

D: the required degree of precision.

Assuming a 95% confidence level, a precision of 5%, and a prevalence of mango producers of 20% within the agricultural population, and incorporating a finite population correction factor [5], the sample size was determined for each of the three strata. This enabled calculation of the total sample size, which was n = 378 for the project area (Korhogo, Sinématiali, and Ferké). A census of producers in the northern region, which is an exportable mango-producing area and the project area, showed that 31% are from Korhogo, 22% from Ferké, and 47% from Sinématiali [6]. This corresponds to 117, 83, and 178 producers from Korhogo, Ferké, and Sinématiali, respectively.

Characteristics of the orchard that influence yield

Doumbia *et al.*'s study in 2016 indicated that over 90% of orchards consist of no more than two plots, with these plots predominantly located within the same physical area. Furthermore, over 90% of these plots are homogeneous in terms of varietal composition. Specifically, the exploratory survey indicates that the Kent variety is overwhelmingly predominant, while the Keith and Amélie varieties are present only in minor proportions. The use of fertilizer among mango producers is minimal, with only approximately 3%. Irrigation practices are also extremely limited among mango producers, as less than 1% utilize irrigation.

Fertilizer is used only marginally by mango producers; in fact, only about 3% of mango producers apply

this input.

Unlike fertilizers, herbicides and insecticides are usually applied by a significant number of producers. In fact, these two inputs are used by 70% and 86% of mango producers, respectively.

3. RESULTS

3.1. Results of the Qualitative Approach

3.1.1. Enhancement of Knowledge and Behavioral Change among Producers

Before assessing the project's impact on improving producers' income, interviews revealed that the project had influenced several other aspects of producers' lives, which in turn directly or indirectly contributed to increased income. Specifically, the project fostered a positive shift in producers' attitudes by raising their awareness of mango quality and its significance for export. Producers also came to appreciate the utility and effectiveness of fruit fly control products in achieving these outcomes.

Moreover, through the implementation of pest trapping systems, the project enabled many producers to identify fruit flies. According to the 2015 baseline survey (Doumbia *et al.*), only about 20% of producers were previously able to identify one of the main pests of mangoes in the region, namely the fruit fly. Interview results indicate that this trend has now reversed, with the majority of producers currently able to identify fruit flies—an important milestone in the organization of pest management efforts.

3.1.2. Extension of the Mango Harvest Season

Based on interview findings, a further major impact of the project, attributable to the use of its products, is the lengthening of the mango harvest season. Previously limited to a maximum of approximately two weeks, the mango season now extends to six or even seven weeks. This substantial extension enables the collection and sale of a significantly larger volume of mangoes. Additionally, many producers reported that the project's interventions have allowed them to retain healthy fruit on the trees for longer periods. As a result, when these mangoes are harvested and brought to market later in the season, they command higher prices compared to the initial harvest period.

3.1.3. Decrease in the Number of Interceptions

The year-to-year decrease in the number of interceptions stands out as one of the project's principal outcomes, although this trend does experience occasional reversals in certain years (Table 1). The overall decline in interceptions should be analyzed in conjunction with the substantial financial investments made by the State in the form of subsidies.

Table 1. Trends in interceptions and state financial commitments over the past five campaigns.

Campaign	Number of interceptions	Amount of state subsidies FCFA
2014	62	
2015	10	1,726,000,000 (*i.e.*, 200,000 liters of Success Bait)
2016	10	99,379 liters of Success Bait (corresponding to the balance of the 2015 subsidy)
2017	33	425,000,000
2018	23	399,993,000
2019	8	

Source: Report on the 2018 Mango Campaign Assessment (DPVCQ).

3.1.4. Enhancement of Producers' Income

A combination of several factors—including increased producer knowledge and improved practices,

an extended mango harvest season, and a reduction in the number of interceptions—has led to a significant rise in producers' income over the past three campaigns within the project area. For example, state intervention through the distribution of "succès appât" contributed to a decline in interceptions. The success of this treatment distribution was such that exporters were able to provide bonuses to producers.

When queried about how they utilize their earnings, producers report, in order of decreasing importance:

- Personal investment in consumer goods, particularly the purchase of motorcycles
- Purchasing land for construction and building homes, and
- Upgrading or replacing their production equipment.

3.1.5. Other Factors beyond Project Intervention That Have Contributed to the Increase in Producers' Income

Following our analysis of the ways in which the project has enhanced producers' income, we deemed it pertinent to examine additional factors, unrelated to the project, that have also played a role in this outcome.

Interview findings highlight three principal factors in this regard: the proactive engagement and support of exporters in facilitating project activities, the motivational effect of pricing incentives, and the active participation of some producers in the certification process.

Producer engagement in supporting project activities has been evidenced by the establishment of producer loyalty to a specific exporter, facilitated through crop advances—in other words, by pre-financing via the provision of treatment products. This arrangement enables exporters to gain a comprehensive understanding of the production environment of their associated producers, allowing them to intervene as needed, either by offering agricultural advice or supplying treatment products. By mutual agreement, the cost of these products is deducted from the producer's output at the point of sale. In some cases, more extensive forms of support are observed, such as assisting producers with the education of their children.

It is also noteworthy that the consistent increase in the purchase prices offered to mango producers has played a significant role in improving their incomes. Specifically, the unit purchase price for a box of mangoes rose from 2200 FCFA in 2015 to 2350 FCFA in 2019, corresponding to an average increase of 30 FCFA per box over the past five marketing seasons.

Finally, participation in the certification process—encompassing the adoption of good agricultural practices, enhancement of product quality, and improvement of producers' working conditions—has frequently been identified as a key factor contributing to increased income for producers.

3.1.6. Durabilité

The long-term viability of the project's initiatives depends on the ability of stakeholders within the mango sector—particularly the producers—to maintain the project's outcomes after external support and interventions have ended. Various categories of factors may threaten this sustainability, including human and socioeconomic factors, agro-ecological conditions, and issues associated with the implementation of control methods.

Human and Socioeconomic Factors

Interviews reveal that some producers exhibit a marked lack of motivation to actively manage their own orchards. They tend to withdraw from direct involvement, delegating all intervention initiatives to factory operators and harvest technicians. This pattern of behavior appears to be typical among most mango producers in Korhogo, who are predominantly retired civil servants and thus occupy a rentier position. While the informal agreement between these producers and the factory operators remains mutually satisfactory, the arrangement may seem advantageous. However, should this tacit contract be disrupted for any reason, producers find themselves ill-equipped to address operational challenges, having been distanced from practical realities for an extended period and lacking the capacity to undertake even basic production improvement measures, particularly those related to controlling mango fruit flies.

Additionally, the dominant role of mango exporters in determining purchase prices has been

identified as a significant source of demotivation among certain producers. This discouragement leads to a general disinterest in adopting improved production techniques, especially those aimed at combating fruit flies.

Agro-Ecological Factors

Historically, research institutions were the sole providers of mango seedlings used for establishing new orchards. While this was the case prior to the crisis, and even more so in its aftermath, there has been a proliferation of private nurseries. Although mango seedlings from these private nurseries are generally more affordable than those provided by research institutions, it is important to highlight that the phytosanitary quality of seedlings from private nurseries is often inadequate. Such seedlings are potential vectors for diseases that may jeopardize mango production.

Additionally, to prevent livestock from straying into young mango orchards, cashew trees are often planted as protective hedges. Observations at harvest time indicate that cashew apples left on the ground serve as significant refuges for fruit flies, which subsequently infest mango crops. If these cashew hedges are not also subjected to appropriate treatment, they can seriously undermine mango production by facilitating fruit fly infestations.

Constraints Associated with the Use of Control Methods

Several constraints are directly associated with the implementation of fruit fly control methods. Limited availability, high costs of treatment products, and the complexity of assembling application equipment are frequently identified as significant barriers to their use. Treatment products are notably expensive; for instance, a box of M3 is priced between 160,000 and 250,000 FCFA. TIMAYE is applied at a rate of 45 sachets per hectare, with each sachet costing 500 FCFA, resulting in a total expense of 22,500 FCFA per hectare. To maintain efficacy, this treatment must be reapplied every three weeks. The Succès Appât product costs 10,000 FCFA per liter, with producers required to contribute 125 FCFA per liter; this treatment must be renewed every ten days. Furthermore, gathering the necessary equipment for product application is often challenging. For example, 45 plastic water bottles per hectare are needed to construct the traps. The substantial volumes of water required for some methods also present a considerable constraint, particularly in regions where water is scarce during certain periods of the year. Additionally, some producers have reported the ineffectiveness of specific treatment products.

From a strictly scientific standpoint, it has been highlighted that the attractants currently used in traps lure and capture only a single genus of fruit fly, specifically the male. (Females, responsible for oviposition in mangoes, are not attracted by sexual lures.) This concerns the genus Bactrocera (species Bactrocera dorsalis). The three other genera—Ceratitis, Dacus, and Zeugodacus—are not targeted by existing traps. The potential emergence and proliferation of species from these three genera represent a significant threat to orchards.

3.2. Results of the Quantitative Approach

3.2.1. Distribution of Mango Producers in the Area According to Different Combinations of Fruit Fly Control Methods

Mango producers employ various combinations of fruit fly control strategies, with each combination represented by different proportions of producers (see Table 2). The first category, comprising approximately 5% of producers, consists of those who do not implement any fruit fly control measures.

Producers in the next three categories each rely exclusively on a single control method: approximately 3% use only sanitation, around 2.65% employ solely food baits, and about 5% utilize only sexual attractants. These groups are mutually exclusive within the sample.

Beyond these three categories, there are three additional groups of producers who employ a combination of two control methods, referred to as binary combinations:

- The group of producers utilizing both food baits and sanitation accounts for approximately 11.75% of the producers in our sample.
- Those who practice combining sexual attraction and sanitation facilities have the highest number,

accounting for about 42% finally.

- The third category involves the combined use of sexual attractants and food baits. This group accounts for approximately 8% of the mango producers in the sample.

The final category consists of producers who employ a combination of three control strategies, referred to as the ternary method, which simultaneously integrates sanitation, sexual attractant-based control, and food bait-based control. This category, which is the second largest, comprises around 23% of the mango producers in our sample (Table 2).

Table 2. Percentage distribution of various combinations of control methods implemented against the fruit fly.

Type of method		Percentage	Standard error of mean (se)	Confidence interval 95%	
				Lower terminal	Upper terminal
	Does not apply any method.	5.16	1.28	3.13	8.37
Simple method	Sanitation (S)	2.98	1.02	1.51	5.82
	Food bait (AL)	2.64	1.02	1.22	5.61
	Sexual attractions (ATR)	4.97	1.31	2.93	8.31
Integrated Pest Management	AL + S	11.74	2.01	8.30	16.34
	ATR + S	41.47	2.66	36.32	46.81
	ATR + AL	7.77	1.55	5.20	11.46
	(AL + ATR + S)	23.25	2.5	18.68	28.55
	Total	100			

3.2.2. Mango Cultivation Areas by Different Pest Control Method Combinations

The average size of a mango orchard is approximately 6 hectares (6.06) (see Table 3). This figure exhibits considerable variation depending on the combination of pest control methods employed, with orchard sizes ranging from 1.5 ha to 12 ha. Producers who utilize only sexual attractants, as well as those who combine sexual attractants with food baits, occupy an intermediate position in terms of orchard size. At the extremes, the largest average orchard sizes are associated with the use of three-method combinations, whereas sanitation and food bait-based control methods are typically employed on comparatively smaller areas (see Table 4).

Table 3. Average area (in hectares) planted with mango trees in the project zone.

	Area Average (ha)	Standard error of the mean (se)	95% confidence interval	
			Lower limit	Upper terminal
Area	6.06	0.49	5.09	7.02

Table 4. Mean mango cultivation area (hectares) in the project region by different combinations of pest management methods.

Type of method	Average area in ha	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
Does not apply any method	3.33	0.93	1.49	5.17
Sanitation (S)	1.91	0.37	1.17	2.66
Food bait (AL)	1.50	0.24	1.01	1.98
Sex appeal (ATR)	5.00	1.07	2.87	7.14
AL + S	3.79	0.45	2.88	4.70
ATR + S	4.51	0.313	3.89	5.13
ATR + AL	5.97	0.917	4.16	7.78
Integrated pest management (AL + ATR + S)	11.86	1.80	8.29	15.43

3.2.3. Estimating Key Economic Performance Indicators

1) Household Mango Sales Volumes and Factor Productivity

On average, each household sold approximately 10 tons of mangoes during the 2019 mango season (Table 5). However, the volume of mangoes marketed varies significantly depending on the combination of fruit fly control methods employed (Table 6). Marketed quantities range from less than 1 ton per household when only the food bait control method is used, to over 20 tons per household when a combination of three control methods is implemented. It is important to note that marketed quantities should be interpreted in relation to the cultivated area, which, as previously mentioned, also varies depending on the combination of control methods used (Table 6).

Table 5. Estimated average quantity of mangoes marketed per household (in tons).

	Average quantity (in tons)	Standard error of the mean (se)	95% confidence interval	
			Lower limit	Upper terminal
Quantity	10.03	1.42	7.21	12.84

Table 6. Estimated average quantity (in tons) sold per household as a function of different combinations of fruit fly management methods.

Type of method	Average quantity (in tons)	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
Does not apply any method	2.99	1.16	0.68	5.30
Sanitation (S)	5.16	2.23	0.75	9.58
Food bait (AL)	0.69	0.08	0.53	0.85

Continued

Sex appeal (ATR)	4.01	1.47	1.10	6.92
AL + S	6.00	0.90	4.21	7.79
ATR + S	7.09	0.59	5.93	8.26
ATR + AL	10.02	2.32	5.42	14.62
(AL + ATR + S)	21.83	5.67	10.63	33.03

2) Yield Levels

The average yield per household is 1.566 tons per hectare (Table 7). On average, mango-producing households harvested 1.56 t/ha of mangoes suitable for marketing during the 2019 mango season (Table 7). Nevertheless, this average masks considerable disparities, as shown in Table 8. Yields range from approximately 0.5 t/ha to over 2 t/ha (Table 8). Four distinct yield groups can be identified through analysis. At one end of the spectrum, the lowest yields are observed among producers employing only a single fruit fly control method, while the highest yields are achieved through the use of the sanitation method. Between these extremes are producers who either do not use any control method or employ binary or ternary combinations of control strategies: Single-method application (exclusive use of one control method): (AL): 0.57 t/ha and (ATR): 0.72 t/ha; No control method: None: 0.93 t/ha; Binary or ternary combinations: AL + S: 1.54 t/ha, ATR + AL: 1.62 t/ha, ATR + S: 1.71 t/ha; AL + ATR + S: 1.64 t/ha; and Sanitation: 2.19 t/ha (Table 8).

Table 7. Average mango yield (tons/ha) in the project area.

	Average yield (in tons/ha)	Standard error of the mean (se)	95% confidence interval	
			Lower limit	Upper terminal
Efficiency	1.56	0.06	1.43	1.69

Table 8. Estimated average yield (tons per hectare) based on various combinations of fruit fly management methods.

Type of method	Average yield (in tons/ha)	Standard error of the mean (SE)	Confidence interval 95%	
			Lower terminal	Upper terminal
Does not apply any method.	0.93	0.27	0.38	1.48
Sanitation (S)	2.19	0.53	1.12	3.25
Food bait (AL)	0.57	0.12	0.32	0.82
Sex appeal (ATR)	0.72	0.11	0.50	0.95
AL + S	1.54	0.15	1.23	1.84
ATR + S	1.71	0.08	1.54	1.88
ATR + AL	1.62	0.25	1.10	2.13
Integrated pest management (AL + ATR + S)	1.64	0.16	1.31	1.97

3) Estimating Input Costs per Hectare Associated with Various Combinations of Control Methods

The implementation of pest control strategies necessitates the use of a range of agricultural inputs. As shown in Table 9, the average expenditure per hectare on these inputs is 54,725 FCFA. Similar to other indicators, this average cost per hectare varies depending on the specific context, with values ranging from approximately 20,000 FCFA to 65,500 FCFA, as detailed in Table 10. On average, sanitation, binary control methods, and ternary control methods incur the highest input costs. In contrast, the costs under the "No Method Applied" scenario reflect only the general agricultural production expenses (see Table 10).

Table 9. Average input costs (in FCFA per hectare) associated with the implementation of various fruit fly control methods in the project area.

	Average input costs in FCFA/ha	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper limit
Input costs_ha	54723.8	3434.05	47941.22	61506.38

Table 10. Estimated average input costs associated with the implementation of various combinations of fruit fly control methods, expressed in FCFA per hectare.

Type of method	Average input costs in FCFA/ha	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
No method applied	19972.69	6942.90	6259.80	33685.58
Sanitation (S)	45310.17	9664.17	26222.54	64397.8
Food baits (AL)	43270	4322.53	34732.6	51807.4
Sexual attractants (ATR)	23889.32	4691.28	14623.59	33155.04
AL + S	44336.64	5405.49	33660.09	55012.78
ATR + S	51559.13	5020.23	41643.71	61474.55
ATR + AL	65580.23	15311.14	35339.32	95821.13
(AL + ATR + S)	80250.63	9547.96	61392.52	99108.74

4) Estimation of Gross Margin per Hectare Associated with Different Combinations of Control Methods

The mean gross margin per hectare is 100,317 FCFA; however, this figure ranges from approximately 17,000 FCFA to 200,000 FCFA, as shown in Table 11 and Table 12. The mean gross margin per hectare serves to divide the eight average gross margin values, each corresponding to one of the eight control method combinations, into two distinct groups. Specifically:

- Sanitation (191,632 FCFA/ha)
- The combination of Sexual Attractants and Sanitation (126,139 FCFA/ha)
- The combination of Sexual Attractants and Food Baits (102,775 FCFA/ha) each yields a gross margin per hectare exceeding the mean value (100,137 FCFA/ha), whereas:
- The combination of Food Baits and Sanitation (95,213 FCFA/ha)
- No Control Method Applied (82,250 FCFA/ha)
- The ternary combination of control methods (65,149 FCFA/ha)
- Sexual attractants applied alone (52,105 FCFA/ha)
- Food baits applied alone (16,897 FCFA/ha) each result in a gross margin per hectare below the mean.

Table 11. Average gross margin per hectare (in FCFA) achieved through fruit fly control measures in the project area.

	Gross margin per in FCFA/ha	Standard error of the mean (se)	95% confidence interval	
			Lower limit	Upper terminal
Gross margin	100,317	9099.46	82342.95	118291.1

Table 12. Estimated gross margin per hectare (FCFA/ha) resulting from the application of various combinations of fruit fly control methods.

Type of method	Margin per hectare in FCFA	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
Does not apply any method.	82250.26	29693.95	23596.16	140904.3
Sanitation (S)	191631.9	58058.47	76949.73	306314.1
Food baits (AL)	16896.67	11029.02	−4888.82	38682.15
Sexual attractions (ATR)	52105.29	13198.25	26034.95	78175.62
AL + S	95213.74	19244.06	57201.18	133226.3
ATR + S	126139.5	10706.79	104990.5	147288.5
ATR + AL	102774.7	31221.12	41104.01	164445.4
(AL + ATR + S)	65149.62	29460.75	6956.171	123343.1

5) Estimating the Total Production Cost Based on Different Combinations of Control Methods

The total production cost per hectare refers to the sum of input costs and the expenses associated with other orchard intensification and maintenance activities (see Table 13 and Table 14). On average, the total production cost per hectare amounts to 76,931 FCFA. However, this average conceals substantial disparities, similar to those observed for other indicators. Specifically, the total production cost per hectare ranges from approximately 20,000 FCFA to 127,840 FCFA.

Among the various control strategies, both ternary and binary combinations of control methods incur the highest total production costs per hectare, in comparison to other approaches. Notably, the average total production cost per hectare associated with ternary control methods is nearly double the regional average (refer to Table 14).

Table 13. Estimation of the total production cost in FCFA per hectare for fruit fly control in the project area.

	Total cost of production in FCFA/ha	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
Total production cost	76,931	6235.88	64613.22	89249.78

Table 14. Estimated total production cost in FCFA per hectare associated with the application of various combinations of fruit fly management methods.

Type of method	Total cost of per hectare in FCFA	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
No method applied	19972.69	6945.99	6251.66	33693.72
Sanitation (S)	56787.64	13529.41	30061.83	83513.46
Food bait (AL)	43270	4320.63	34735.08	51804.92
Sexual attractions (ATR)	24279.74	4772.79	14851.63	33707.85
AL + S	70491.27	13759.45	43311.03	97671.51
ATR + S	71582.8	6126.04	59481.49	83684.11
ATR + AL	65118.03	16761.66	32007.26	98228.8
(AL + ATR + S)	127838.3	22134.74	84113.64	171,563

6) Estimating Net Benefit per Hectare According to Different Combinations of Control Methods

On average, mango producers in the region obtain a net benefit of approximately 95,000 FCFA (94781.51) per hectare (see Table 15). However, this figure is subject to considerable variation depending on the specific context. Binary combinations of control strategies, as well as sanitation measures, offer mango producers the highest net benefits, which are equal to or exceed the average net benefit.

In contrast, the simplest combinations of control methods, the reference case of "No Control Method Applied", and the ternary combination of control methods result in the lowest net benefits per hectare. These net returns fall below the average net benefit (see Table 16).

Table 15. Estimated net benefit (in FCFA) per hectare for fruit fly control in the project area.

	Net profit per ha in FCFA	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper limit
Net income	94781.51	9192.17	76623.4	112939.6

Table 16. Estimated net profit per hectare in CFA francs based on different combinations of fruit fly control methods.

Type of method	Net profit per ha in FCFA	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
Does not apply any method.	82250.26	29692.91	23595.25	140905.3
Sanitation (S)	183719.1	58943.51	67282.83	300155.3
Food baits (AL)	16896.67	11033.02	−4897.81	38691.14
Sexual attractions (ATR)	51714.87	13189.99	25659.53	77770.2
AL + S	94497.95	19367.91	56238.83	132757.1
ATR + S	118440.2	11066.21	96580.18	140300.3
ATR + AL	102668.5	31207.57	41021.52	164315.6
(AL + ATR + S)	57193.42	29445.72	−973.2661	115360.1

7) Estimating the Value of a Workday Based on Different Combinations of Control Methods

The results show that, on average, mango cultivation in the region values an agricultural workday at 5085 FCFA, compared to an average wage labor cost of 1000 FCFA (Table 17).

The mean value attributed to a workday varies substantially depending on the combination of pest control methods used, ranging from over 14,000 FCFA to less than 1000 FCFA. Sanitation practices yield a high valuation for the workday, whereas the ternary control method results in the lowest valuation, at less than 600 FCFA. In the case of binary combinations, there is considerable variability in the workday's valuation. The use of sexual attractants alone values the workday at over 14,500 FCFA, a figure that appears abnormally high (Table 18).

Table 17. Average value of a workday in FCFA.

	Valuation of the working day in FCFA/d	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
Value	5085.77	1176.27	2759.31	7412.24

Table 18. Workday valuation based on various combinations of fruit fly control strategies.

Type of method	Enhancing the working day in FCFA	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper terminal
Sanitation	9643.686	1365.898	6942.117	12345.19
Food bait	5228.88	10140.53	−14527.31	25585.09
Sexual attractions	14581.26	4149.56	6374.15	22788.37
AL + S	2143.12	558.812	1037.88	3248.35
ATR + S	7072.09	1636.69	3834.99	10309.2
ATR + AL	3858.01	9207.50	−14352.82	22068.85
(AL + ATR + S)	757.28	1214.29	−1644.37	3158.93

8) Estimating the Economic Efficiency of Mango Producers

The analysis reveals that the average unit cost of mango production is 74.92 FCFA per kilogram, while the average selling price is 108.50 FCFA per kilogram. Based on these calculations, approximately three-quarters of mango producers in the region can be classified as economically efficient. In contrast, around 20% of mango producers are identified as operating at a deficit (see Table 19).

As shown in Table 20 below, the Sinématiali area has the highest proportion of efficient producers, followed by the Ferkéssedougou area. In comparison, the Korhogo area has the largest concentration of mango producers operating at a deficit relative to the other two zones.

Table 19. Estimation of producers' economic efficiency.

Efficient producer	Percentage	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper limit
Deficit	22.42	2.44	17.97	27.61
Effective	77.58	2.44	72.39	82.03
Total	100			

Table 20. Assessment of the economic efficiency of producers according to the production zone.

Zone	Level of economic efficiency		Total
	Loss-making producers	Efficient producers	
Korhogo	36.73	**63.27**	100
Sinématiali	12.82	**87.18**	100
Ferkéssedougou	28.57	**71.43**	100
Total	22.42	77.58	100

Two key performance indicators were selected to better evaluate the economic efficiency of mango producers in the region: export yield and the average production cost (average input cost) per hectare.

Efficient producers achieve export yields of mangoes that are twice as high as those recorded by deficit producers (Table 21).

With respect to average input costs per hectare, the findings reveal that efficient mango producers incur average input costs per hectare that are half those of their inefficient counterparts (Table 22). This disparity has a direct effect on net profit per hectare. The net profit per hectare for efficient mango producers is substantially higher than the regional average, whereas inefficient producers experience a significantly negative net profit per hectare. This group of producers thus operates at a loss (Table 23).

Table 21. Mango export yield levels based on producer economic efficiency.

	Average yield in t/ha	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper limit
Regional average	1.56	0.06	1.43	1.69
Efficient producer	1.79	0.07	1.64	1.95
Loss-making producer	0.80	0.06	0.65	0.94

Table 22. Average input costs per hectare based on producers' economic efficiency.

	Average input Of inputs per hectare	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper limit
Regional average	54723.8	3434.05	47941.22	61506.38
Efficient producer	45476.19	3392.43	38759.97	52192.4
Producer losses	90459.28	9234.72	71671.1	109247.5

Table 23. Net profit per hectare for mango producers according to their efficiency status.

	Net profit per hectare	Standard error of the mean (se)	Confidence interval 95%	
			Lower terminal	Upper limit
Regional average	94781.51	9192.17	76623.4	112939.6
Efficient producer	137646.7	7747.54	122341.5	
Producer losses	−82805.04	21077.85	−124444.1	−41165.99

4. DISCUSSION

The assessment of the Fruit Fly Control Project (PLMF) in Côte d'Ivoire has yielded significant findings regarding both the economic outcomes and agricultural practices of mango producers. Analysis of the collected data indicates that the implementation of integrated pest management strategies has led to marked enhancements in yields, net income, and labor productivity among the producers.

4.1. Enhancement of Agricultural Performance

The findings indicate that the mean yield increased from 1.15 t/ha in 2015 to 1.56 t/ha in 2019, corresponding to a 26.37% rise. This improvement is primarily attributed to the combined application of integrated pest management techniques—including sanitation, sexual attractants, and food baits—with binary and ternary combinations demonstrating clear superiority over single-method approaches. These results support the earlier work of [2], which demonstrated that integrated management strategies are more effective than isolated methods in reducing infestations and enhancing yields.

4.2. Economic Viability of Control Methods

Sanitation-only methods yielded the highest average gross margin (191,632 FCFA/ha), followed by binary combinations such as sexual attractants plus sanitation (126,139 FCFA/ha). Conversely, the ternary combination, despite its effectiveness in yield improvement (1.64 t/ha), resulted in a lower net benefit (57,193 FCFA/ha) due to elevated production costs (127,838 FCFA/ha). These findings are consistent with the observations of [4], who noted that the profitability of agricultural practices depends not only on yield but also on the management of operational costs.

4.3. Economic Efficiency and Producer Profiles

The analysis of economic efficiency revealed that 77.58% of producers operate efficiently, with an average production cost (45,476 FCFA/ha) significantly lower than that of less efficient producers (90,459 FCFA/ha). These efficient producers also achieve nearly double the export yields and report a net profit of 137,646 FCFA/ha, in contrast to an average loss of 82,805 FCFA/ha among inefficient producers. This observation corroborates the findings of [3], who highlighted the critical role of technical expertise and input management in driving the economic performance of agricultural enterprises.

4.4. Sustainability and Implementation Constraints

The study identifies significant challenges to the long-term sustainability of pest control method adoption, especially in the absence of subsidies. Economic barriers (such as high input costs and water scarcity) and logistical difficulties (including implementation complexity) threaten to undermine the project's achievements over the medium term. These findings underscore the need for supportive interventions, notably ongoing technical assistance and targeted input subsidy policies. This aligns with the recommendations of the [7], which stress the importance of incentive-based public policies to ensure the sustainability of integrated protection technologies.

4.5. Stakeholder Involvement and Future Perspectives

The active participation of exporters, the training provided to producers, and the certification process have also played a critical role in enhancing income levels. These findings indicate that the success of agricultural development initiatives depends on a holistic approach that engages all segments of the value chain, in accordance with the recommendations of [8] in their analysis of agricultural systems.

5. GENERAL CONCLUSION

This study demonstrates that the implementation of the PLMF has generated an overall positive effect

on the incomes of mango producers. Among the strategies assessed, the promotion of integrated pest management—particularly sanitation measures and binary combinations, emerges as the most cost-effective. Nevertheless, the sustainability of these achievements is jeopardized by reliance on subsidies and ongoing technical challenges. It is therefore imperative to reinforce public policy support for the sector, ensure the continuous dissemination of best practices, and enhance access to high-quality inputs. Such measures are crucial to consolidating the progress made and fostering inclusive and sustainable growth in Côte d'Ivoire's mango sector.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

REFERENCES

1. Ministère d'État Ministère de l'Agriculture Développement Rural et des Productions Vivrières (2024) Statistiques agricoles de la Direction de Productions Végétales et du Contrôle Qualité 2024.
2. Vayssières, J.F., Korie, S., Coulibaly, O. and Temple, L. (2009) The Effectiveness of Bait Sprays in Controlling Mango Fruit Flies in Benin. *Journal of Applied Entomology*, **133**, 405-415.
3. Stessens, B. and Doumbia, S. (1998) Compétitivité des principales cultures dans la région de Dikodougou, Nord de la Côte d'Ivoire Concepts et méthodologies d'élaboration des budgets de culture. Analyse économique de la production fruitière en Côte d'Ivoire. CNRA, 22.
4. Harouna, K. (2005) Intensification Agricole et répartition des revenus sur les périmètres rizicoles en période de libéralisation du marché du riz au Niger. Africa Rice Center (WARDA) Rice Policy and Food Security in sub-Saharan Africa, 100-124.
5. Naing, L., *et al.* (2006) Problèmes pratiques dans le calcul de la taille de l'échantillon pour les études de prévalence. *Archives des sciences orofaciales*, **1**, 9-14.
6. Doumbia, S., N'klo, H., Magloire, M.Y. and N'goran, A. (2016) La situation de référence des indicateurs de performance au niveau des producteurs de mangues du Nord de la Côte d'Ivoire. Rapport d'étude, 72.
7. FAO (2013) Sustainable Crop Production Intensification through an Ecosystem Approach and an Enabling Environment: Policy Support Guidelines.
8. Trébuil, G., *et al.* (2002) Systèmes agraires et développement: Analyse d'une démarche interdisciplinaire. IRD Éditions.