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RESEARCH ARTICLE OPEN ACCESS

Complementing assisted pollination with artificial pollination in oil palm crops planted with interspecific hybrids O × G (*Elaeis guineensis* × *Elaeis oleifera*): Is it profitable?[☆]

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Abstract – A total of 70 000 hectares have been dedicated to the cultivation of the interspecific hybrid O × G in Colombia as of 2020. There was a need to introduce what is known as “assisted pollination” for these O × G crops. In 2018, the Colombian Oil Palm Research Center (Cenipalma) released artificial pollination, which consists of applying naphthaleneacetic acid (NAA) as a complement to assisted pollination, with the goal of promoting the formation of oil in parthenocarpic fruits. Given the recent introduction of artificial pollination, a research study was proposed with the objective of analyzing the cost-benefit relationship from introducing artificial pollination, both during the cultivation and oil extraction stages. From a methodological point of view, the costs per unit were estimated based on the outcome from plantations in the Colombian Urabá region using two different treatments: the first consists of carrying out assisted pollination during anthesis (applying *E. guineensis* pollen when the flowers are receptive); the second consists of complementing assisted pollination with NAA application at 7 and 14 days after anthesis. The results indicate that the use of NAA increases net income by 7.7% per hectare of crop. Furthermore, the production costs of a metric ton of palm oil decreases by −9% mainly due to the increase in the oil extraction rate.

Keywords: profit / cost per unit / parthenocarpic fruits / oil extraction rate / productivity

Résumé – Compléter la pollinisation assistée par la pollinisation artificielle dans les cultures de palmiers à huile plantés d’hybrides interspécifiques O × G (*Elaeis guineensis* × *Elaeis oleifera*) : est-ce rentable ? Un total de 70 000 hectares a été consacré à la culture de l’hybride interspécifique O × G en Colombie à partir de 2020. Il était nécessaire d’introduire ce que l’on appelle la « pollinisation assistée » pour ces cultures O × G. En 2018, le Centre colombien de recherche sur le palmier à huile (Cenipalma) a lancé la pollinisation artificielle, qui consiste à appliquer de l’acide naphtalène-acétique (NAA) en complément de la pollinisation assistée, dans le but de favoriser la formation d’huile dans les régimes parthénocarpiques. Compte tenu de l’introduction récente de la pollinisation artificielle, une étude de recherche a été proposée dans le but d’analyser la relation coût-bénéfice de l’introduction de la pollinisation artificielle, tant au niveau de la culture que de l’extraction de l’huile. D’un point de vue méthodologique, les coûts par unité ont été estimés sur la base des résultats de plantations de la région colombienne d’Urabá utilisant deux traitements différents : le premier consiste à effectuer une pollinisation assistée pendant l’anthèse (application de pollen d’*E. guineensis* lorsque les fleurs sont réceptives) ; le second consiste à compléter la pollinisation assistée par une application de NAA à 7 et 14 jours après l’anthèse. Les résultats indiquent que l’utilisation de NAA augmente le revenu net de 7,7 % par hectare de culture. En outre, les

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coûts de production d'une tonne métrique d'huile de palme diminuent de 9% principalement en raison de l'augmentation du taux d'extraction d'huile.

Mots clés : profit / coût unitaire / régimes parthénocarpiques / taux d'extraction d'huile / productivité

1 Introduction

The cultivation of interspecific hybrids O × G (*Elaeis oleifera* × *Elaeis guineensis*) has become a common alternative in Colombian Oil palm production. O × G cultivars need assisted pollination. Assisted pollination consists of the controlled release of pollen from *E. guineensis* on female inflorescences of O × G cultivars in anthesis, is necessary in order to guarantee the formation of commercially usable FFB (Sánchez *et al.*, 2011). The introduction of assisted pollination requires plantations to have a larger number of workers because of the need to apply pollen to each inflorescence in anthesis (phenological stage 607) (Daza *et al.*, 2020).

1-naphthaleneacetic acid (NAA) is already widely used in agriculture, especially in the production of apples, peaches, tomatoes, mandarins, and other crops, where its application has been reported to contribute to the promotion of reproductive phases (flowering and fruiting) (Singh and Mirza, 2017), the induction of parthenocarpy, increase in fruit weight, and decrease in seed production (Liu *et al.*, 2016).

In 2018, Cenipalma released the results of artificial pollination in O × G palms, which consisted of applying NAA to female inflorescences during anthesis and up to 15 days after anthesis (daa). The experimental results from applying 1200 ppm of NAA in a liquid medium to inflorescences during and after anthesis found that it resulted in the development and filling of fruits, as well as a 15% increase in the number of harvested bunches (Romero *et al.*, 2021).

In Colombian plantations, the adoption of NAA occurred by the end of 2018, and at the beginning, most plantation managers decided to implement only artificial pollination. It has been evident that the application of NAA results in lower labor yields compared to assisted pollination, because the same inflorescence is treated three times (artificial pollination) instead of one (assisted pollination) (Romero *et al.*, 2021).

The greater number of parthenocarpic fruits per bunch has generated an increase in the OER, ranging from 3 to 5 percentage points (increase in output by 13% to 22% by using artificial pollination). These fruits have a higher mesocarp content and, therefore, a higher oil content (Daza *et al.*, 2020). However, the increase in parthenocarpic fruits has an effect on decreasing the pressing capacity at the mill (Fernández, 2013) due to the higher fiber content and lower seed content.

Given that the adoption of this technique has generated changes in the production process during both the cultivation and fruit processing stages, the objective of this work was to determine the economic impact of the adoption of NAA on the business of hybrid O × G cultivation.

2 Materials and methods

The study was carried out in Oil Palm Plantations in Urabá Antioqueño (7.7575, −76.660). To assess the economic impact of the use of NAA on hybrid O × G production, we compared the economic performance of two different treatment scenarios:

- Scenario 1. A plantation in the Urabá region cultivating the Coarí × La Mé cultivar performs assisted pollination during anthesis.
- Scenario 2. A plantation in the Urabá region cultivating the Coarí × La Mé cultivar performs assisted pollination during anthesis and artificial pollination using NAA 7 daa and 14 daa.

For this purpose, a cost-benefit analysis was carried out for the crop and palm oil mill that considers the two proposed scenarios. Palm plantations with hybrid O × G cultivars in the Urabá are characterized by excellent agronomic management, in addition to regular abundant rainfall ranging from 2000 to 3500 mm per year (Mantilla, 2016). The collection of data was carried out during cultivation and in the palm oil mill because the treatments effect fruit production and oil extraction.

2.1 Economic indicators

The indicators used to compare the economic effects of applying NAA are shown in Table 1. The method used to estimate each indicator is described below. It is worth mentioning that the indicators were estimated based on prices from 2019.

2.1.1 Production cost per metric ton of FFB ($\$ \text{ t FFB}^{-1}$)

The production costs of the crop were estimated following the methodology proposed by Mosquera *et al.* (2019). This methodology involves building an income and expenses flow for the crop; costs are then estimated by crop stages: establishment (year 0), unproductive (from year 1 to year 3), development (from year 4 to year 6) and, maturity (years 7 to 30). It is considered that a palm planting project has a lifespan of about 30 years.

The costs are estimated based on information regarding cultivation-related activities. Factors including labor (labor performance, frequency of each activity, and daily payment), required inputs (quantities and prices), the use of capital goods (machinery and tools), the opportunity cost of land (land use value), technical assistance payments and, management (8% of total variable costs) (Newnan *et al.*, 2012; Mosquera *et al.*, 2016).

The figures used for the construction of the flow of income and expenses correspond to those reported by the Urabá plantations for the year 2018 (Mosquera *et al.*, 2019), and the prices were updated for 2019 by considering the price index (Banco de la Republica de Colombia, 2020).

The yield (t FFB ha^{-1}) for each period was estimated using historical information from the Urabá plantations, where the data were collected. The cash flow in the scenario with assisted pollination complemented with artificial pollination was based

Table 1. Economic performance indicators.

Indicator	Equation	Variables
Cost per ton of FFB/USD t FFB^{-1}	$CFFB = \frac{\sum_{t=0}^{30} C_t}{\sum_{t=0}^{30} Y_t}$	C_t = Crop management costs per ha, during period t (2019 prices). USD ha^{-1}
Annual net income from the crop (NIC)/USD$ ha^{-1}	$\frac{\text{NIC} = \text{p}\sum_{t=0}^{30} (Y_t) - (CRFF * Y_t)}{30}$	Y_t, crop yield, during period t (2019 prices). t FFB ha^{-1} p, average price of a ton of fruit in 2019 t refers to a period between year 0 and year 30
Cost per ton of crude palm oil (CPO)/USD$ t CPO^{-1}	$CCPO = \frac{E + CFFB}{OER}$	E, cost of extracting the oil off from a metric ton of FFB in 2019. ($ t FFB^{-1}) OER, Oil Extraction Rate $pCPO$, average price of a ton of crude palm oil
Annual net income per hectare equivalent to oil/USD$ ha^{-1}	$(Y_t * OER_t) * (pCPO - CCPO)$	

Table 2. Parameters used.

Assumption	Price	Unit	Source
Price per ton of oil	564	USD t CPO^{-1}	Average reference price from the agriculture industry for 2019 after taxes and fees
Price per ton of fruit	96	USD t FFB^{-1}	17% of the price paid for a ton of oil
Kernel price	183	USD t Kernel^{-1}	Average reference price from the agriculture industry for 2019 after legal deductions
Shell	15	USD t^{-1}	2019 price

on the results obtained by these plantations for weight and number of bunches.

The unit cost was estimated based on the ratio between the sum of the costs per hectare over 30 years, and the amount of fruit produced in the same area and the same period (Tab. 1).

2.1.2 Net income from the crop

This indicator estimates the difference between the income from the sale of FFB and the costs per unit of area (hectare) for a given period (year). The income estimate is based on the production of one hectare per scenario, and the average reference price paid for one ton of fruit in 2019 was considered in both cases (Tab. 2). In addition, given the long lifespan of the crop, the average cost of a ton of fruit over a 30-year period was also considered.

The annual net income because it is a commonly-used indicator for palm growers in Colombia. The grower is not considered as having incurred debt when developing their investment, and, as such, debt payments need not be considered. This assumption is because, upon consideration, the effects of artificial pollination would become less clear, and a great deal of heterogeneity was observed with respect to the percentage of investment that was made with credit.

2.1.3 Cost per ton of CPO ($ t CPO^{-1})

This indicator includes the costs of processing the fruit and the raw materials. The process costs are: extractor depreciation, energy consumption, labor, and maintenance. The values from the production cost study done by Mosquera *et al.* (2019) were used. The crop production cost was taken into account when estimating the price of raw materials. The assumption here is that one entity has both a plantation and a palm oil mill. This assumption is valid because, thus far, the combination of assisted and artificial pollination has been adopted mainly by companies owning oil palm crops and a palm oil mill).

Additionally, two important technical aspects in estimating the cost of oil were researched: The OER, and the kernel extraction percentage. The OER is a weight-to-weight ratio, where the weight of the extracted oil is used as the numerator, and the weight of the FFB used to extract the oil is used as the denominator (Noor, 2002). The kernel extraction percentage is a weight-to-weight ratio between the recovered cleaned and dry kernel (numerator) and the weight of the FFB from which the kernel was recovered (denominator).

The kernel and shell make up the seed. When the bunches are processed, these parts are necessary to consider because they constitute an important source of income as by-products. The kernel for one is sold to facilities that extract palm kernel oil (an in-demand product in the cosmetics industry) and that sell palm kernel cake (animal supplements). As for the shell, its calorific value means it is widely used for combustion in steam cogeneration equipment (Sue, 1992).

2.1.4 Net income from one hectare in terms of oil

This indicator estimates the income from one hectare of oil palm crops, assuming an integrated plantation-mill structure. For this purpose, the gross income generated by the sale of the

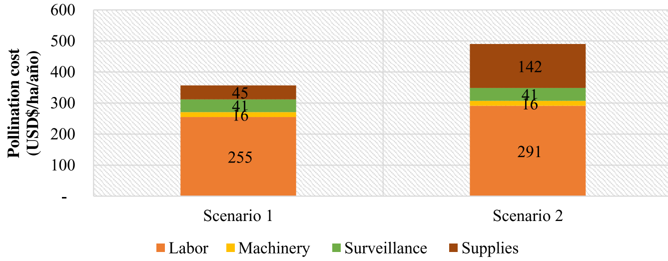

Fig. 1. Costs associated with pollination according to the method.

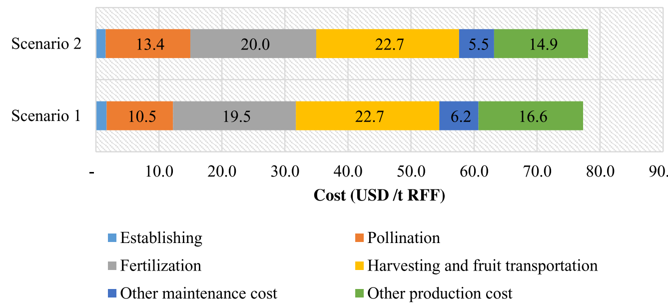

Fig. 2. Long-term unit production cost by category.

Table 3. Economic indicators for O × G crop in the adult stage in both scenarios.

Category	Unit	Scenario 1	Scenario 2	Difference*
Number of bunches per hectare (mature crops)	#	2042	2414	18.2%
Average bunch weight	kg bunch^{-1}	17.8	16.9	−5.1%
Average annual crop yield (mature crops)	t FFB ha^{-1}	36.4	40.9	12.4%
Average unit cost per t FFB	USD t FFB^{-1}	77	78	1.3%
Annual gross income (mature crops)	USD ha^{-1}	3489	3920	12.4%
Annual cost per ha (mature crops)	USD ha^{-1}	2811	3190	13.5%
Annual net income (mature crops)	USD ha^{-1}	678	730	7.7%

*Difference = (Scenario 2 value – Scenario 1 value) / Scenario 1 value, expressed in percentage.

oil produced per hectare of the crop in each scenario is calculated (Tab. 1). The production cost of the amount of oil produced in per hectare of land is deducted from the gross income. The assumptions regarding the prices used are displayed in Table 2.

2.2 Pollination cost

The application of NAA (artificial pollination) as a complement to assisted pollination was a practice rapidly adopted by some Colombian plantations that have hybrid O × G cultivars starting from 2018. "Pollination cost" describes the costs associated with pollination, addressing both scenarios: 1) assisted pollination, and 2) assisted pollination complemented with artificial pollination (Fig. 1).

The pollination costs are presented in Figure 1, covering both methods. From this, a cost estimate of USD 357/ha per year was calculated when only assisted pollination is carried out. The cost of performing assisted pollination, complemented with two reinforcements of NAA at 7 daa and 14 daa, is 37% higher, for a total of USD 490/ha per year.

The increase in the cost of pollination work is a result of the lower labor productivity because each inflorescence is treated three times instead of once. This results in more inflorescences per pollination day, so the cost of labor increased by 14%. This is because assisted pollination can be carried out over 12 ha per day per person, with the same area visited three times a week (24 ha assigned to each worker). Assisted pollination reinforced with two NAA applications (artificial pollination) can only be carried out over 7 ha per day per person, with the same area being visited twice a week (21 ha assigned to each worker).

Concerning the inputs, the cost increase was estimated to be 215% when complementing artificial pollination with two applications of NAA. The estimated costs were USD 0.02 per flower when pollen is applied (0.3 g of pollen and 2.7 g of talc) and USD 0.058 per flower when using NAA (0.3 g of pollen and 2.7 g of talc/flower during anthesis and 0.24 g of NAA 7 daa and 14 daa). The difference in the cost of the inputs lies in the fact that, in assisted pollination, only one pollen application is made to the inflorescence; meanwhile, when complemented with two NAA reinforcements, the pollen is applied, and then the NAA is applied twice (three applications to the inflorescence).

3 Results

3.1 Production cost per metric ton of FFB

In Urabá plantations, complementing assisted pollination with two reinforcements of NAA (Scenario 2) increases the number of bunches produced per hectare by 18%, compared to the scenario where only assisted pollination was used (Scenario 1). This is because NAA reinforcements allow for pollination of an additional 10% of inflorescences, as the timeframe during which pollination can be carried out is now extended. This is the opposite of what happens with assisted pollination, which can only be performed during anthesis (Leguizamón *et al.*, 2019). Additionally, NAA reinforcements reduce bunch failure (when bunches start forming, but their fruits do not ripen) compared to the scenario in which only assisted pollination was performed (Pérez and Arias, 2018). On the other hand, studies carried out in the Eastern Palm Tree Zone of Colombia by Leguizamón *et al.* (2019) showed that the exclusive use of NAA decreased the average bunch weight

(ABW) by −5.1% due to a lower formation of seeds in the fruits when compared to conventional assisted pollination.

For the analysis performed, parameters relating to the number of bunches and the average weight were taken into account. The Urabá plantations provided these data for both scenarios. In Scenario 2, this means an 18% increase in the number of bunches and a 5% decrease in the average weigh. The results showed that the crop yield (expressed as t FFB/ha per year) increased by 12.4% in Scenario 2 compared to Scenario 1. It is worth mentioning that the yields obtained by Urabá crops under the two pollination treatments correspond to the adoption of better agricultural practices in different crop management processes, and is not exclusively due to the pollination process (Mantilla, 2016).

The FFB production cost per ton, estimated based on the ratio between the maintenance cost over 30 years for the lifetime of the crop and the productivity of one hectare over the same period (Tab. 1), was 1% higher in Scenario 2 than in Scenario 1 (Tab. 3). While production costs per hectare increase when complementing assisted pollination with NAA reinforcements 7 daa and 14 daa, so does productivity (Tab. 3).

Figure 2 shows the most important categories during production that contribute to the cost of producing one metric ton of fruit. It is worth mentioning that the pollination cost per metric ton of FFB is 27% higher when using NAA reinforcements as compared to Scenario 1 (assisted pollination only). Likewise, the cost of fertilization is 2.5% higher in Scenario 2 compared to Scenario 1, mainly due to the larger amount of fertilizer necessary to address nutrition requirement, needed by the plant, in order to meet the demand by the extra inflorescences generated by the NAA treatment.

3.2 Net income from the crop in one year during the adult stage (USD $ ha^{-1})

The yield from a plantation in the adult stage in one year and, the 2019 average price for a ton of FFB in Colombia were used. It was estimated that in the adult stage for Scenario 2, the net income from the crop increases by 7.7% compared to that of Scenario 1 (Tab. 3). These positive results can only be achieved with the proper application of NAA to the inflorescences (*e.g.*, by well-trained operators) at the appropriate doses. In this sense, good results will only be achieved if proper agronomic management of the crop is assured. This includes ensuring good nutrition (adequate nutrient availability and soil moisture), timely control of pests, and harvest criteria aimed at maximizing the oil content. As such, if agronomic management, implementation conditions, and training of the operating personnel are inadequate, cost overruns that could considerably reduce the income margin may arise (Leguizamón *et al.*, 2019).

3.3 Production cost per ton of CPO

This indicator was calculated for both scenarios. Differences in the processing of the fruit bunches were identified between Scenario 1 and Scenario 2. The bunches from Scenario 1 (treated exclusively with assisted pollination) are characterized as having parthenocarpic fruits make up over 50% of the total number of fruits in a bunch. These fruits can constitute up to 35% of the oil yield from the bunch, with an oil potential of up 22% having been observed (Rincón *et al.*, 2013; Garcia-Nuñez *et al.*, 2019). When Scenario 2 is implemented (pollination assisted with two reinforcements of NAA 7 dda and 14 daa), the proportion of parthenocarpic fruits relative to the total number of fruits in a cluster increases, reaching 71.2%–80.3% (Leguizamón *et al.*, 2019). The oil potential can be as high as 35%, so long as the bunches are harvested at their optimum maturity stage (stage 807–809) 4 (Sinisterra *et al.*, 2019).

In the case of Urabá, an average OER of 20.6% was reported for the years 2014 to 2018 when Scenario 1 was implemented, and an OER of 27.5% was obtained for Scenario 2. This implies that, per ton of fruit, an additional 69 kg of oil is extracted in Scenario 2, which translates to an additional 33.5% of oil per ton of processed fruit. This concurs with results reported by Romero *et al.* (2021), who found that the fruits that were treated with assisted pollination had an OER that was somewhere around 20.5%. Once NAA was introduced, an increase of up to 5 percentage points was recorded in the OER – this means that an additional 20% of oil was extracted per ton of fruit (Romero *et al.*, 2021). The Palmeiras extraction plant, when using NAA, reached an OER of 26%; on the other hand, the OER did not exceed 21% when the treatment was assisted pollination only (Ruíz *et al.*, 2020).

The palm oil mills that currently operate in Colombia are designed for the processing FFB from *E. guineensis* cultivars. As such, when processing O × G FFB (which have a lower seed content in Scenario 1 and almost no seed in Scenario 2), they face difficulties in pressing the fruits, and therefore suffer a decrease in pressing capacity. The latter is due to the higher fiber content in the bunch (because of the increase in parthenocarpic fruits), which is why strategies such as adding seeds or shells have been implemented to make pressing more effective (Fernández, 2013). This inefficiency and the need to add materials that facilitate pressing (husk, shell, seeds) will increase the cost of processing one ton of fruit. This is even more evident in fruits pollinated using NAA. According to the reports from palm oil mills in the country, pressing capacity is reduced by at least 15%.

The extraction cost of one ton of oil was estimated using data obtained from the Urabá palm oil mill on OER and the kernel extraction percentage. The price paid for the raw materials (t FFB) is treated as the production cost of the crop, with results displayed in Table 3 for both scenarios.

Table 4 shows the parameters used to estimate the cost of production of one ton of oil. A decrease in processing capacity for the fruit in Scenario 2 has been accounted for. The same kernel extraction value was used for both scenarios because assisted pollination is used in Scenario 2 and, consequently, there will be seed formation.

The production cost for a ton of CPO in Scenario 2 is 9% lower than in Scenario 1 (Fig. 3). It was calculated by subtracting to the CPO production costs from Scenario 2 from the CPO production costs of Scenario 1. This difference was divided by the CPO production costs from Scenario 1. This decrease in production costs is mainly due to the lower amount of FFB required to obtain a ton of CPO, resulting from the higher OER (Fig. 3).

Table 4. Parameters used to estimate the production cost of CPO.

Category	Unit	Scenario 1	Scenario 2
Installed processing capacity	t FFB hour^{-1}	12	12
Decrease in processing capacity	%		−15
Weight of added shells/1 ton of FFB	%	10	10
Oil Extraction Rate (OER)	%	23.7	27.3
FFB to obtain a ton of oil	t	4.22	3.66
Weight of kernels in tons/1 ton of FFB	%	2.5%	2.5%

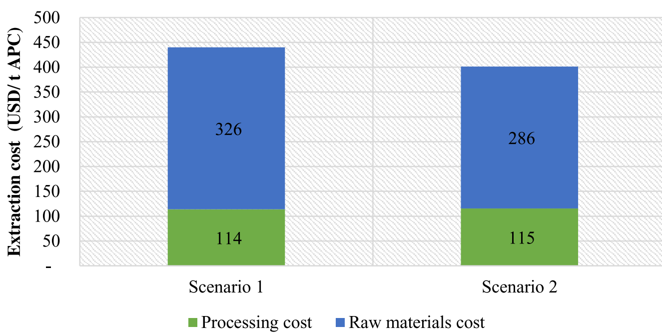

Fig. 3. Production cost of a ton of CPO.

Table 5. Annual net income from one hectare in terms of oil production (mature crops).

Category	Unit	Scenario 1	Scenario 2	Difference*
Amount of oil	t CPO ha^{-1}	8.6	11.1	29%
Cropping costs	USD ha^{-1}	2811	3190	13%
Milling costs	USD ha^{-1}	979.0	1288	32%
Total costs	USD ha^{-1}	3790	4478	18%
Gross income	USD ha^{-1}	4864	6296	29%
Net income	USD ha^{-1}	1074	1818	69%

3.4 Net income from a hectare in terms of oil

Average reference prices paid for a ton of CPO in 2019 after taxes and fees, as well as the results obtained in previous sections, were taken into account for this portion of the analysis. Furthermore, the equivalent in CPO of the FFB production per hectare was also taken into consideration. This assumes that the same company engages in both the cultivation and extraction sides of the business.

Table 5 summarizes the indicators *via* which the net income generated is calculated for each of the scenarios at a hectare level. Total costs per hectare of crop are higher when implementing NAA reinforcements because of the increase in the cost of pollination, the larger amount of fertilizer required to cope the greater production of FFB and the increase in harvest and transportation costs. These changes yield an increase of 13% in cropping costs (Tab. 5). On the other hand, the costs of extracting oil from the RFF produced in a hectare increases because of the larger amount of metric tons produced per hectare when using NAA reinforcements, this leads to an increase of 32% in the milling costs when comparing Scenario 2 with respect Scenario 1. Adding up cropping costs and milling costs per hectare, one obtains an increase in production costs of 18%. However, this increase in production costs is offset by a larger increase in the gross income, which was estimated in 29%.

Finally, Scenario 2 yields an income that is 69% higher than Scenario 1, which is markedly higher. This clarifies the profitability of complementing assisted pollination (during anthesis) with two NAA reinforcements (7 dda and 14 daa) and explains why, in companies that have both hybrid O × G plantations and a palm oil mill, artificial pollination has been rapidly adopted.

4 Conclusions

Artificial pollination with the application of naphthalene-acetic acid (NAA) is an economically viable method for increasing the productivity and profitability of the hybrid O × G Coarí × La Mé palm oil crop as long as proper agronomic management of the crop is guaranteed, which is the case for the Urabá plantations that this study focused on.

Some of the benefits observed upon the implementation of this treatment include the formation of bunches that would otherwise not have formed from assisted pollination alone. This compensates for the additional costs in inputs and labor. In fact, the cost of producing a metric ton of FFB was 1.3% greater when implementing NAA reinforcements (Scenario 2) with respect to using exclusively assisted pollination (Scenario 1). Nonetheless, in Scenario 2 there is an increase in the production of FFB of 12.4%, which translates into an increase of the same magnitude in gross income. This implies that O × G planters may benefit from implementing NAA reinforcements.

Regarding the mill, in Scenario 2 it was observed a decrease in processing capacity of −15%, given the increase in the proportion of parthenocarpic fruits entering the oil extraction process. However, the observed increase in the oil extraction rate (OER) leads to a smaller amount of FFB required to produce a metric ton of CPO (from 4.22 in Scenario 1 to 3.66 in Scenario 2). Therefore, the total cost per ton of CPO decreases in −9% in Scenario 2, compared to Scenario 1, since less raw material (*i.e.* FFB) is required. Note, more economic benefit may be obtained by implementing technologies tailored to improving the process of extracting oil from bunches that are dominated by parthenocarpic fruits.

Artificial pollination shows clear benefits for FFB producers. However, properly executed treatment (*via* trained and competent personnel), use of adequate tools, and application of the recommended doses must all be guaranteed. Moreover, crops must receive proper fertilization and effective management of pests (weeds, pests, and diseases), and harvesting must be carried out by following the criteria to identify the optimum harvest time, which corresponds to the phenological stage in which the oil content that can be extracted by the palm oil mill is maximized. If all these conditions are not met, it may result in cost overruns that considerably reduce the net income margin of the producers.

Disclosure

This manuscript has not been published and is not under consideration for publication elsewhere. We have no conflicts of interest to disclose.

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