

Assessing labor productivity in the harvest of crops planted with *Elaeis oleifera* x *Elaeis guineensis* crossings in an oil palm plantation from Colombia[☆]

Jhonatan Eduardo Camperos-Reyes¹ , Sonia Sánchez-Rodríguez², Néstor Fernando Pulido-Álvarez², Elizabeth Ruiz-Alvarez¹  and Mauricio Mosquera-Montoya^{1,*} 

¹ Research Results Validation Unit, Colombian Oil Palm Research Center (Corporación Centro de Investigación en Palma de Aceite - Cenipalma), Calle 98 No. 70-91, 14th Floor. Bogotá, Colombia

² Agronomic Unit, Palmas Monterrey S.A.S, km 7 way to Puerto Wilches - El Pedral. Santander, Colombia

Received 16 November 2023 – Accepted 25 June 2024

Abstract – In Colombia, crossings of *Elaeis oleifera* by *Elaeis guineensis* (OxG hybrids) were planted after Bud Rot outbreaks. These OxG hybrids had not been planted before, so management practices were adapted from those developed for *Elaeis guineensis* crops. The harvest of fresh fruit bunches (FFB) is one of the tasks with the greatest share on production costs and the most labor demanding in an oil palm plantation. The objective of this study was to bridge the knowledge gap on the measurement of harvest performance for OxG hybrid to ensure crop sustainability. Therefore, a time and motion study, and its corresponding costs analysis were developed for an OxG cultivar in a plantation in the Colombian oil palm growing Central Zone. We found out that on average, cutters spend 40.4% of their effective working time inspecting oil palm bunches to assess if they are at optimal harvest time (OHT), compared to 15.9% taken for *E. guineensis*, likely because OxG hybrid harvest requires the consideration of three harvest criteria. Labor productivity in terms of the tons of FFB harvested, increased by 55% from low to high productivity lots, but the area covered by workers decreased by 51.7%. The latter suggests that the number of harvest operators should be assigned according to crop yield. Furthermore, it was observed that labor productivity for harvesting OxG crops in this study fell within the range of values reported for *E. guineensis* harvest in Colombia. Notwithstanding, the harvest criteria for OxG hybrid of more than 3 meters high need improvement to overcome the difficulty of inspecting bunches.

Keywords: Time and motion study / Oil Palm / crop yield / *Elaeis guineensis* / *Elaeis oleifera* x *Elaeis guineensis*

Résumé – Évaluation de la productivité du travail lors de la récolte de palmiers à huile issus de croisements *Elaeis oleifera* x *Elaeis guineensis* en Colombie. En Colombie, des croisements entre *Elaeis oleifera* et *Elaeis guineensis* (hybrides OxG) ont été plantés suite à des épidémies de Bud Rot (pourriture du cœur). Ces hybrides OxG n'avaient jamais été plantés auparavant, et les pratiques ont dû être adaptées à partir de celles développées pour *Elaeis guineensis*. La récolte des régimes de fruits frais (FFB) est l'une des tâches qui pèse le plus sur les coûts de production et qui demande le plus de travail. L'objectif de la présente étude était de combler le manque de connaissances sur l'efficacité de la récolte pour les hybrides OxG, afin d'assurer la durabilité de la culture. Les temps de travail et de déplacements ont été mesurés, et les coûts correspondants ont été analysés pour un cultivar OxG dans une plantation située dans la zone centrale de culture du palmier à huile en Colombie. Nous avons constaté qu'en moyenne, les coupeurs passent 40,4 % de leur temps de travail effectif à inspecter les régimes de palmier à huile pour évaluer s'ils sont à la période optimale de récolte (OHT), contre 15,9 % pour *E. guineensis*, probablement parce que la récolte des hybrides OxG nécessite la prise en compte de trois critères de récolte. La productivité du travail, en termes de tonnes de FFB récoltées, a augmenté de 55 % entre les lots à faible et à forte productivité, alors que le périmètre couvert par les travailleurs a diminué de 51,7 %. Ce résultat suggère que le nombre d'opérateurs de récolte devrait être calculé en fonction du rendement de la récolte. En Colombie, la productivité de la main-d'œuvre

[☆] Contribution to the Topical Issue: “Palm and palm oil / Palmier et huile de palme”.

*Corresponding author: mmosquera@cenipalma.org

mesurée pour la récolte des hybrides OxG est de l'ordre de celle décrite pour *E. guineensis*. Les critères de récolte utilisés pour les hybrides OxG de plus de 3 mètres de haut devront toutefois être améliorés, car l'observation détaillée des régimes de fruits est délicate à cette hauteur.

Mots clés : Étude du temps et des déplacements / palmier à huile / rendement / *Elaeis guineensis* / *Elaeis oleifera* x *Elaeis guineensis*

Highlights

- Results of a study on the harvesting process of oil palm crops planted with OxG hybrids (OxG) are presented.
- The goal was estimating indicators on labor productivity for OxG. OxG crops have been planted at commercial scale for about 15 years and there is little research on their labor yields.

1 Introduction

Crude palm oil (CPO) is an edible vegetable oil with the highest demand worldwide, above soybean and canola oil (LMC International Ltd., 2011). In 2021, 35.5% of the vegetable oils consumed across the world was CPO (United States Department of Agricrop Foreign Agricultural Service, 2022). The largest CPO producers in the world are in Southeast Asia. In fact, Indonesia and Malaysia together contribute around 88.4% to the global palm oil production. Colombia contributes only 2.3% (FAOSTAT, 2022) as such, Colombian producers act as price takers.

In 2023, oil palm in Colombia contributed to 17.6% of the agricultural gross domestic product (GDP) of the country and created about 191,000 direct and indirect jobs, consolidating itself as a key sector for the Colombian economy (Federación Nacional de Cultivadores de Palma de aceite, 2022a, 2022b, 2023). In addition, 82.4% of the total number of workers hired by oil palm companies in Colombia earn more than 1.5 times the minimum wage and enjoy social payments (retirement fund, housing subsidies, health coverage, and paid holidays). This proportion is way higher than the 20% of Colombian rural workers that have access to social payments and whose earnings average 0.6 the minimum wages (Federación Nacional de Cultivadores de Palma de Aceite, 2021).

The Colombian oil palm agro-industry has been threatened by various diseases, and bud rot (BR) (causal agent: *Phytophthora palmivora*) is the most limiting disease in the cultivation of the African oil palm (*Elaeis guineensis*) in Colombia (Martínez *et al.*, 2010). Some *Elaeis oleifera* × *Elaeis guineensis* (OxG) interspecific hybrid cultivars have shown partial resistance to BR, allowing the replanting of oil palm in regions attacked by BR (Navia *et al.*, 2014). Moreover, the oil extracted from OxG hybrid cultivars has better market potential to buyers searching for higher proportion of unsaturated fatty

acids (Mozzon *et al.*, 2020). Besides, OxG hybrids are characterized by slow growth, indicating that they have a longer crop life cycle than *E. guineensis* cultivars (Corley and Tinker, 2016; Forero *et al.*, 2012; Torres *et al.*, 2004).

In terms of crop management, the major changes in switching from *E. guineensis* to OxG hybrids are seen in pollination and harvest. OxG female inflorescences require assisted pollination to ensure adequate conformation of the bunches, however it is desirable to implement artificial pollination with naphthalene acetic acid to improve bunch formation and fruit set (Mosquera-Montoya *et al.*, 2023, Romero *et al.*, 2021; Sánchez *et al.*, 2011). On the other hand, harvesting OxG crops imply training the personnel on cutting FFB at the proper phenological stage, which requires recognizing the optimal harvest time (Caicedo *et al.*, 2020; Henson, 2012; Rincón *et al.*, 2013). Since harvest and pollination are highly demanding in terms of costs, an increase in labor efficiency have considerable effect on crop profitability (Mosquera-Montoya *et al.*, 2022; Ruiz *et al.*, 2022).

Most literature on oil palm harvest relates to *E. guineensis* cultivars. In this regard, alternatives aimed at optimizing the yields of the employed labor in Colombia have been assessed by means of time and motion studies for cutting and collecting FFB. In a study by Mosquera-Montoya *et al.* (2008), the harvest performed by two operators (cutter and collector) was compared with the harvest performed by a single operator, and the result showed that two operators have the potential to reduce the cost of harvest by 17%. Another study, which focused on the reduction of search time for ripe bunches via the marking of bunches ready for cutting prior to harvest, showed a 71% increase in the number of bunches harvested (Mosquera and Fontanilla, 2006). Furthermore, mechanized systems for harvesting oil palms have proven to increase labor productivity (Shuib *et al.*, 2020). A study that compared manual collection of FFB and collection with a “grabber” showed that the grabber reduced the cost of harvesting a ton of FFB by 10.4% during the period of high crop productivity (Munévar *et al.*, 2020).

While a plethora of literature exists on studies done on *E. guineensis*, the authors had access to one study on OxG crops performed by Ruiz Álvarez *et al.* (2020). In that study, the use of a mechanized cutter was compared with that of chisel, and the mechanical cutter resulted in a 15% decrease in the cost of cutting a ton of fresh fruit bunches (FFB) (Ruiz Álvarez *et al.*, 2020). With the reality of a dearth in literature for OxG crops, our study therefore helps in filling a gap in literature on assessing labor productivity for the harvest of the OxG hybrid crops. Moreover, the results of this study provide parameters and indicators for the optimization of the OxG hybrid harvest.



Fig. 1. Harvesting of OxG hybrid by two operators. The picture on the left shows a FFB cutter using a chisel to cut off a bunch. The picture on the right shows a FFB collector who gathers the FFB in a cart pulled by a water buffalo.

2 Materials and methods

2.1 Location

The study was performed on the interspecific hybrid of OxG (Brasil × Djongo) oil palm from the Palmas Monterrey S. A.S plantation located in the municipality of Puerto Wilches (Colombia), with coordinates 7°17'55" N 73°53'05" W. The study gathered data from the harvest of a 435 hectares (ha) oil palm plantation with 10 years old palms and a mean bunch height of 2.5 m. The average annual temperature was 36 °C, the average relative humidity was 97%, and the annual rainfall ranged between 2500 and 2800 mm.

2.2 General description of harvest work

In Palmas Monterrey, harvest teams are composed of two field operators. The first field operator (the cutter) is in charge of cutting off FFB from the palms, whereas the second field operator (*i.e.* the collector) collects FFB from the floor and loads them onto a cart pulled by a water buffalo. [Figure 1](#) presents workers carrying out FFB cutting and FFB collecting.

2.2.1 Tools and personal protective equipment

The main tool used by the cutter is the chisel. It is an alloy of iron with a sharp end that is 12.7 cm wide. The chisel is attached to a stainless-steel pole of approximately 1.9 m long. The cutter is provided a 22.9 cm sharpening stone to keep the tool sharp. The collector has a machete and a triangular steel file to sharpen the tool. Furthermore, the harvest team receives a water buffalo with its respective cart for FFB transportation ([Fig. 2](#)).

Regarding the personal protective equipment (PPE), the operators wear a Type I – class E helmet to protect their head

from being struck by leaves or bunches. They are also provided with gloves to avoid getting injured by FFBs thorns and leaf thorns. In addition, they receive leather or rubber boots with steel toes to protect their feet ([Fig. 2](#)).

2.2.1.1 Harvesting activities

There are activities required to perform the assigned task that are not part of the task itself. Activities such as receiving instructions, receiving/returning the harvesting equipment, tools preparation (sharpening), inner transportation to/from the assigned lot, and waiting for the bus to depart to their living locations; are considered in the activities flowchart ([Tabs. 1 and 2](#)), and of course, their frequency is low.

2.2.1.2 Cutting off FFB from oil palms

Cutting off FFB activities flowchart also comprised those activities performed at each palm in which FFB cutting is done. Naturally, these activities are as frequent as the number of palms harvested. To cut FFB from an oil palm, a FFB cutter walks from one palm to the next and, performs an inspection in search of FFB at optimal harvest time (OHT). If there are bunches to be harvested, they cut the frond holding the FFB and then they cut off the FFB from the palm ([Tab. 1](#)).

2.2.1.3 Collecting FFB at harvested palms

The Activities flowchart comprises those activities performed at each palm in which FFB collection is done. In the search of cut FFB, a collector walks through the field with a water buffalo pulling a cart (in which FFB are transported). Once a FFB is found on the ground, the FFB collector proceeds to cut its peduncle, chops the fronds cut by the FFB cutter, and arranges them around the oil palm circle. Finally, the collector picks up the



Fig. 2. Tools and personal protective equipment used by the harvest team. Cutter: 1. chisel and 2. sharpening stone. Collector: 3. machete, 4. triangular file and 5. water buffalo (livestock) with cart. Personal protective equipment (harvest team): 6. type 1 – class E helmet, 7. meat gloves, 8 and 9. leather or rubber boots with steel toes.

FFB and places it in the cart. When the cart is full of FFB, collector must head towards the FFB collection points where FFB are gathered before trucks take harvested FFB to the oil palm mill (Tab. 2).

2.3 Documentation of the harvesting process

Time and motion study was performed in two stages. In the first stage a Motion Study was carried out while the second stage corresponds to the Times Study. The methodological aspects of both are described.

2.3.1 Motion study

2.3.1.1 Activities flowchart

The motion study describes all activities performed by operators throughout their working day. That is, from the moment they enter the plantation until they exit from it. Six harvest teams were followed during three full working days for the motion study purposes. With the data gathered it was possible to build the activities flowchart.

Note that some activities are repeated along the working day at each palm harvested. These activities correspond to the actual task assigned to field operators at each oil palm tree (either FFB cutting or FFB collection). For example, inspecting oil palms in the search for ripe bunches, cutting fronds, cutting FFB and arranging cut fronds are frequent activities performed by the FFB cutter in a working day and correspond to activities carried out at each harvested palm. However, some other activities are necessary to carry out the job but their frequency is lower. For instance, gathering/returning back equipment, receiving instructions and heading towards/from the assigned lot, are activities that happen once a day (Camperos *et al.*, 2020).

2.3.1.2 Supplements and strange elements

“Strange elements” are those activities that delay work processes and do not constitute part of the job. Among them are phone calls, conversation, equipment repair because of damage, etc. Supplements are a time compensation for those activities necessary for the well-being of the operators.

Table 1. Activity flowchart for FFB cutter.

Activity number*	Activity name	Description
5	Preparation activities	At the warehouse, the FFB cutter receives equipment and instructions on the assigned lot. Proceeds to prepare tools and personal protective equipment.
10	Moving within the lot	Any move within the lot that is required to begin cutting FFB.
15	Walking from palm to palm	Movement between one palm and another.
20	Inspection	Searching for bunches in OHT to harvest.
25	Decision making	Are there bunches to harvest? If yes, proceed with activity 30, and if no, proceed with activity 15.
30	FronD cutting	Cut the frond that holds the bunch.
35	Bunch cutting	Cut the bunch from palm.
40	Decision making	Does the bunch need to be arranged? If yes, proceed with activity 45, and if no, proceed with activity 50.
45	Bunch to traffic path	Place the bunch on the traffic path.
50	Decision making	Are the assigned tasks finished? If yes, proceed with activity 55, and if no, proceed with activity 20.
55	Decision making	Does the collector need help? If yes, proceed with activity 60, and if no, proceed with activity 65.
60	Providing support to harvest teammate**	Time permitting, FFB cutter helps his harvest teammate by placing fronds, cutting FFB peduncles, and picking FFB.
65	Return of equipment	Going to the warehouse to return tools, equipment.
70	Waiting for company bus	Waiting for transportation to return home.
75	End of the working day	

* Note that activities are numbers in multiples of 5, so if a process needs to be improved or modified (re-engineering) it would receive a number in between multiples of five.

** This help is provided because both operators of the harvest team are paid by metric ton of FFB delivered at the FFB collecting point.

Table 2. Activity flowchart for a FFB collector.

Activity number*	Name of the activity	Description
10	Preparation activities	At the warehouse, the FFB cutter receives equipment and instructions on the assigned lot. Proceeds to prepare tools and personal protective equipment. It also includes preparing the water buffalo and assembling the cart to it. Then they proceed to the assigned lot.
15	Moving within the lot	Any move within the lot that is required to begin collecting FFB.
20	Moving along the lot in the search of cut FFB	Movement along the harvest road, looking for FFB cut by their harvest teammate.
25	Decision making	Are there bunches to pick? If yes, proceed with activity 30, and if no, proceed with activity 55.
30	Arrangement of fronds	Chop cut fronds and place frond pieces around the oil palm circle.
30	Cutting of peduncles	Cut FFB's peduncle.
40	Bunch picking	Pick up FFB from the ground and place it in the cart.
45	Decision making	Is the cart full? If yes, proceed with activity 50, and if no, proceed with activity 20.
50	Go towards the FFB collecting point and unload FFB	Move to FFB collecting point to unload bunches.
55	Decision making	Are the assigned task finished? If yes, proceed with activity 60, and if no, proceed with activity 20.
60	Return of equipment	Going to the warehouse to return, tools, equipment.
65	Waiting for company bus	Waiting for transportation to return home.
70	End of the working day	

* Note that activities are numbers in multiples of 5, so if a process needs to be improved or modified, it would receive a number in between multiples of five.

Among them are feeding (breakfast and lunch), hydration, rest, personal needs, etc. In addition, supplements account for a time compensation due to fatigue caused by heat, humidity, required concentration and, workload. In this study, both strange elements and supplements were observed throughout the workday, so there was no need to estimate supplements time compensation, it was part of the data recorded.

2.3.2 Time study

2.3.2.1 Sample size (n_0)

The minimum number of palms (sample size) needed to record time activity, was estimated using Equation (1). Equation (1) corresponds to a simple random sampling and it was used at a confidence level of 95% and a relative error of 3% (Hernández Rendón *et al.*, 2022).

$$n_0 = \frac{z^2 * s^2}{E^2} \quad (1)$$

where, z : 95% confidence level (two-tailed normal distribution table = 1.96), s^2 : sample variance, and E : absolute error (resulting from the multiplication of the relative error and the sample mean). The sample parameters were estimated: FFB cutter (mean time= 16.8 s, variance= 190.44 s²) and FFB collector (mean time= 15.5 s, variance= 213.16 s²).

In consequence, the minimum number of palms that will be required to gather time records for activities carried out to cut off FFB was estimated at 2,880 palms. On the other hand, it was estimated that a minimum of 3,787 palms was required to gather time records for FFB collection. Nonetheless, the research team decided to record time data from many more palms than the minimum required to improve the statistical robustness of the data analysis and to take advantage of having human resources already hired and trained on time data gathering. Hence, data was gathered from 22,226 palms for FFB cutting and 22,202 palms for FFB collection.

For the times study, two different analysts recorded data from 17 different harvest teams for a period of 33 working days. Specifically, if the analyst recorded data on FFB cutting for a whole working day, at the next day he/she would gather data on FFB collection. Analyst rotation was in place to reduce observation bias.

2.3.2.2 Data registration

Android CyberTracker application (version 3.515) was installed on mobile devices (Smartphones). CyberTracker allows the design of forms to gather time records. These forms were built based on the activities workflows previously identified, and the Motion study (one for FFB cutting and one for FFB collection) (Hernández Rendón *et al.*, 2022). The field data obtained during a working day were downloaded and stored in digital files (.xls).

2.3.2.3 Analysis of time records

The data collected were analyzed using the Microsoft Excel (Version 2205) and R Studio (version 492) statistical

package. We adapted the methodological approach by Camperos *et al.* (2020) in which palms were classified according to the number of inflorescences to treat per palm (from 0 to 4). It was also necessary for the harvest, because some palms may have more than one FFB to be harvested and, it has an effect on the total time for treating an oil palm tree.

2.4 Work performance and costs

Labor productivity was estimated from two different standpoints. The first was the area covered by a harvest team in a working day (ha/work group) and the second related to the metric tonnes of FFB harvested in a working day per team (t FFB/man-day). Three typologies were established based on crop yield (high, medium, and low production). These typologies were defined by the number of FFB to be harvested per hectare (FFB/ha), that is, 75 FFB/ha for high yield, 45 FFB/ha for medium yield, and 25 FFB/ha for low yield. Based on the mean FFB weight reported by the plantation (15.2 kg/bunch), it was estimated that in a hectare, a harvest team would find 1.14 t FFB/ha (high), 0.684 t FFB/ha (medium), and 0.38 t FFB/ha (low).

The cost of harvesting per hectare was estimated from the payment per ton of FFB harvested reported by the plantation in 2021 (USD 10 / t FFB). This payment includes social payments. The average conversion rate to US dollar considered was 3,982 Colombian pesos (COP) per 1 US dollar. The conversion rate was obtained from historical data reported by the Central Bank of Colombia (Colombia, 2022).

3 Results

3.1 Time and motion study

3.1.1 Motion study – Activity flowchart for the FFB cutter and the FFB collector

Tables 1 and 2 show the activities performed by the FFB cutter and the FFB collector during a working day. The activities are presented in an orderly sequence. A regular font represents a joint activity that are required but not are part of the activities performed at each palm during the harvest (nor cutting, nor collection). Bold letters represent individual activities of the FFB cutter and the FFB collector. Bold letters on a gray background correspond to activities carried out at each palm in which FFB cutting and/or FFB collection was performed.

3.1.2 Time study

3.1.2.1 Duration of working days for the cutter and the collector

A working day for the harvest operators begins at 6 am and lasts for a mean duration of 8.13 h (8 h and 8 min) for the FFB cutter and 8.23 h (8 h and 14 min) for the FFB collector. Preparation activities lasts on average 1.02 h (1 h and 1 min) for a FFB cutter and 1.39 h (1 h and 23 min) for a FFB collector, corresponding to 12.5% and 16.8% of their workday, respectively (Tabs. 3 and 4). The 22-min difference between the two operators is due to the collector getting ready the water buffalo – cart.

The effective working time for FFB cutting (activities from 15 to 60 in Tab. 3) lasts on average 3.15 h (3 h and 9 min)

Table 3. Duration (h) and contribution (%) of activities performed by the FFB cutter during a working day.

Process number	Activity name	Time (h)	Contribution (%)
5	Preparation activities	1.02	12.5%
10	Movements in the lot	0.33	4.1%
15	Walking from palm to palm	0.73	8.9%
20	Inspection	1.27	15.6%
30	Fronde cutting	0.42	5.2%
35	Bunch cutting	0.45	5.6%
45	Bunch to traffic path	0.27	3.3%
60	Providing support to harvest teammate	0.01	0.1%
65	Return of equipment	0.68	8.4%
70	Waiting for company bus	0.98	12.0%
–	Strange elements	0.33	4.0%
–	Supplements	1.65	20.3%
	Total	8.14	100%

Table 4. Duration (h) and contribution (%) of activities performed by the FFB collector during a working day.

Process number	Activity name	Time (h)	Contribution (%)
10	Preparation activities	1.39	16.9%
15	Movements in the lot	0.23	2.8%
20	Moving along the lot in the search of cut FFB	1.37	16.6%
30	Arrangement of fronds	0.48	5.8%
35	Cutting of peduncles	0.30	3.6%
40	Bunch picking	0.59	7.2%
50	Go towards the FFB collecting point and unload FFB	0.72	8.7%
60	Return of equipment	0.63	7.6%
65	Waiting for company bus	1.06	12.9%
–	Strange elements	0.32	3.9%
–	Supplements	1.15	14.0%
	Total	8.24	100%

equivalent to 38.7% of a working day. The effective working time of the FFB collector (activities from 20 to 50 in [Tab. 4](#)) lasts on average 3.46 h (3 h and 28 min) equivalent to 41.9% of a working day.

FFB cutters waited on average 0.98 h (59 min) for the bus that take them home while FFB collectors waited for 1.06 h (1 h and 4 min). It represents 12% and 12.9% of their working day, respectively. Regarding, strange elements and supplements they sum on average 1.98 h (2 h and 8 min) for a FFB cutter and 1.47 h (1 h and 28 min) for a FFB collector; equivalent to 24.3% and 17.9% of the working day, respectively ([Tabs. 3 and 4](#)).

3.1.2.2 Supplements time for a FFB cutter and a FFB collector

During a workday, supplements for a FFB cutter accounted for 1.65 h (1 h and 39 min) equivalent to 20.3% of their working day. Supplements for an FFB collector accounted for 1.15 h (1 h and 9 min) equivalent to 14% of their workday. Resting took the most of supplements time with 74% for the FFB cutter and 72% of the FFB collector. Food intake took 13% of the supplements time for the FFB cutter and 10% of the

supplement time of the FFB collector. Hydration took 8% of a FFB cutter supplements time and 14.5% in the case of the FFB collector. Finally, personal needs time took on average 3% of the supplement time for the FFB cutter and 2% of the supplements time of the FFB collector.

3.1.2.3 Strange elements along a working day of FFB cutters and FFB collectors

Strange elements took 19 min and 48 s for the FFB cutter (4% of the whole working day) and 19 min and 12 s for the FFB collector (3.9% of their whole working day). For the FFB cutter the most strange elements time was due to conversation and, waiting for harvest teammates to start working. For the FFB collector, the most strange elements time was due to waiting for coworker, followed by conversations, cart adjustment, and phone calls.

3.1.2.4 FFB cutter: elapsed time per palm

[Table 5](#) shows the median time spent on activities according to the number of bunches cut. Results showed that a FFB cutter spends 38.6% (3.14 h or 3 h and 8 min) of their

Table 5. FFB cutter: median time spent (seconds) on activities according to number of bunches cut.

Types of palm (categories)	Walking from palm to palm (s)	Inspection (s)	Fronde cutting (s)	Bunch cutting (s)	Bunch to road (s)	Total (s)*	Number of palms
Without FFB	3	3				6	16,277
1 FFB	3	9	7	6	6	31	4,706
2 FFB	3	12	13	13	10	51	1,096
3 FFB	3	15	19	20	14	71	129
4 FFB	5	20	28.5	24	25	102.5	18

* Total elapsed time per palm results from the sum of activities medians.

Table 6. FFB Collection: median time spent (seconds) on activities according to number of bunches cut.

Palm type (categories)	Movement and Search (s)	Peduncle cutting (s)	FFB Pick-up (s)	Arranging fronds at palm circle (s)	Total (s)*	Number of work cycles
without FFB	6				6	16,357
1 FFB	5	4	8	9	26	4,585
2 FFB	5	8	17	16	46	1,102
3 FFB	5	11	27	21	64	137
4 FFB	6	20	33	22	81	21

* Total elapsed time per palm results from the sum of activities medians.

Table 7. Yield of labor and costs per hectare observed. Performance of work is expressed as tons per man-day under different crop yields for a single harvesting day.

Crop yield	Number of bunches per hectare in a day	t FFB/ha in a day	Covered area (hectares/work group) in a day	Yield (t FFB/man-day)	Yield (t FFB/work group) in a day	Labor cost (USD / hectare per day)
Low	25	0.380	7.81	1.48	2.96	\$3.8
Medium	45	0.684	6.20	2.12	4.24	\$6.9
High	75	1.140	4.04	2.30	4.6	\$11.5

working day performing FFB cutting activities (effective work time). Inspection of palms to find FFB at OHT took the most effective work time, with 40.4% (1.27 h or 1 h and 16 min), followed by walking from palm to palm, with 23.2% (0.73 h or 44 min and 5 s). In addition, frond cutting, bunch cutting, and relocating FFB demanded 36.3% (1.14 h or 1 h and 8 min) of the effective work time (Tab. 3).

The elapsed time of cutting FFB from a palm depends upon the number of FFB at OHT on that specific palm. This explains why it ranged from 6 s at palms without FFB (just inspection) to 102.5 s for palms with four FFB to cut (the maximum number of FFB in a palm observed in this study) (Tab. 5). Frond cutting and FFB cutting time increased by 6 and 7 s respectively for each additional FFB. Furthermore, the time to relocate the bunch to the road increased by an average of 4 s for each additional bunch.

3.1.2.5 FFB collection: elapsed time per palm

A FFB collector spends 33.2% (2.74 h or 2 h and 44 min) of their working day performing FFB collecting activities (effective work time). Walking along the field in

the search for cut FFB takes the most of their effective labor time with 50.7% (1.37 h or 1 h and 22 min). The time for collecting the cut FFB on average is 0.59 h (35 min and 2 s) representing 21.5% of their effective time. In addition, cutting the peduncle, chopping fronds and arranging the frond pieces around the harvested palm circle took 0.78 h (46 min and 9 s) representing 28.4% of their effective work time (Tab. 4).

It takes a FFB collector 6 s to pass by a palm without bunches and 81 s to collect FFB from a palm with four bunches (Tab. 6). Time spent on cutting peduncle increases by 3–4 s on average for each additional FFB. The time for picking FFB and loading it in the cart increases by 10 s for each additional bunch. Finally, arranging the fronds around the palm circle increases by 5–7 s for each additional bunch.

3.2 Crop yield and labor costs

Labor yield, expressed in terms of harvested tons of FFB per worker in a working day (t FFB/man-day), varied by

0.82 t FFB/man-day between low and high productivity lots. Specifically, from 1.48 to 2.30 t FFB/man-day, respectively. However, in low productivity lots, the work groups reported an increase of 48.2% in the covered area, that is, from 4.04 to 7.81 ha/work group (high and low productivity, respectively) (Tab. 7).

Given that the plantation manages a single rate of payment per ton of FFB harvested (*i.e.* USD 10/t FFB), it was observed that the cost of harvesting per hectare increases as the productivity of the lot increases. At a low crop yield scenario lot, the actual costs of harvesting are USD 3.82/ha per day and at a high crop yield scenario lot the actual costs of harvesting is USD 11.45 /ha per day.

4 Discussion

Results of this study as well as literature on harvesting of *E. guineensis* cultivars bunches are discussed. Specifically, the logistics used; activities performed; operations, work cycles, working hours, and times used to perform the tasks; and labor yields in terms of FFB harvested per man per day were considered (Ruiz *et al.*, 2022).

The harvest work groups in the OxG hybrid in this study conformed to the groups reported for *E. guineensis* cultivars. The harvest work group comprised a cutter who was in charge of selecting and cutting the bunch at optimal harvest time and a collector who was responsible for cutting the excess peduncle of the bunch and loading them in a cart. In some cases, the work group included another operator, called “seeder”, to collect loose fruits (Fairhurst *et al.*, 2019; Henson, 2012; Ismail *et al.*, 2015; Mosquera-Mosquera-Montoya *et al.*, 2008).

The bunch is frequently harvested with a chisel-type tools such as those used for harvesting *E. guineensis* cultivars of less than 3 m high or less than 6 years after sowing. The tool is the same despite the fact that the OxG hybrid fronds are thicker and more difficult to cut than the *E. guineensis* fronds (Fairhurst *et al.*, 2019; Henson, 2012; Ng *et al.*, 2013; Ruiz Álvarez *et al.*, 2020; Ruiz *et al.*, 2022). However, mechanized implements are used for both *E. guineensis* and OxG hybrid cultivars because manual harvesting requires high energy consumption and worker skills. In *E. guineensis* cultivars, mechanized cutters such as CKat or Cantas have been successfully used for palms less than 5 m high (Shuib *et al.*, 2011), and in the OxG hybrid, the PC70 mechanized shovel has been used as an alternative for bunch cutting (Ruiz Álvarez *et al.*, 2020).

The same types of fruit transport systems are used for movement to the collection point for *E. guineensis* and OxG hybrid cultivars. However, there are transport systems involving the use of livestock with carts, as well as involving the use of semi-mechanized systems (tractors) or mechanized grabber-type or cable-track hoists (Fairhurst *et al.*, 2019; Fontanilla *et al.*, 2010; Ismail *et al.*, 2015; Mosquera-Mosquera-Montoya *et al.*, 2008; Munévar *et al.*, 2020; Shuib *et al.*, 2020).

Effective labor time was lower for OxG hybrid (3.15 h/man-day) than that reported for *E. guineensis* cultivars (7.45 h/man-day) of medium height (6–11 m) (Mosquera and Fontanilla, 2008). The cutter took 40.4% of the effective labor time to inspect the bunches; however, the time is high

compared to the travel and inspection time reported for *E. guineensis* cultivars (15.9%) (Mosquera and Fontanilla, 2008). The difference in these inspection times is mainly because *E. guineensis* cultivars require only one harvest criterion (number of detached fruits), whereas OxG hybrid requires three criteria (number of detached fruits, opacity of color, and fruit cracking) (Caicedo *et al.*, 2020; Henson, 2012). Moreover, the palm height (3 m) of the OxG hybrid has a negative effect on the inspection time. This implies that the harvest criteria for OxG hybrid cultivars more than 3 m high need improvement or adjustment to facilitate quick identification of FFB in OHT.

The estimated labor yields in this study were associated with the availability of fruits in the lots, indicating that a low availability of FFB (0.380 t FFB/ha) allows an average harvest of 1.48 t FFB/man-day; and a possible harvest of 55% more FFB can be achieved by workers in fewer hectares with three times higher productivity. Similar results were observed in harvest studies performed on *E. guineensis* cultivars and assisted pollination in OxG hybrids, in which labor yields were related to bunch density and inflorescences per hectare present in the lots (Camperos *et al.*, 2021; Fontanilla *et al.*, 2010). These findings indicate that the assigning of staff for harvest work must be dynamic and adjusted according to the timing of lot productivity.

In Malaysia, harvesting of *E. guineensis* cultivars performed using manual harvest systems have reported labor yields between 0.7 and 1.1 t FFB/man-day (Ismail *et al.*, 2015). Our results indicate a range between 1.4 – 2.3 t FFB/man-day, which is close to the 1.8 – 2.0 t FFB/man-day reported for Colombian plantations with high yields (25–30 t FFB/ha/year) (Ruiz *et al.*, 2022). However, when mechanized knives were used to cut the bunches, reports on Malaysian labor yields are 2.2 and 2.5 t FFB/man-day (Ismail *et al.*, 2015). Other mechanized harvest studies from Indonesia, Bangladesh, and Nepal reported average yields of 3, 2.7, and 2.34 t FFB/man-day, respectively (Ahmad *et al.*, 2017).

A strange element that affects labor yield the most is the length of the waiting time for the bus that convey workers home. As mentioned in the results section it ranged between 0.98 h and 1.06 h. As a consequence, company managers were advised to work on improving the field operators bus transportation logistics.

5 Conclusions

A working day for harvest operators lasts 8.13 h for the FFB cutter and 8.23 h for the FFB collector. Preparation activities take on average 1.02 h for a FFB cutter and 1.39 h for a FFB collector. Strange elements and supplements add on average 1.98 h for a FFB cutter and 1.47 h for a FFB collector. Waiting for the bus to take them home, FFB cutters spend on average 0.98 h while FFB collectors waited for 1.06 h. All these activities are necessary for harvest operators to perform their activities. However, they are not part of the task assigned. Note that after discounting all these times the effective working time on FFB cutting is on average 3.15 h and 3.46 h for FFB collecting.

Effective working time is the target that needs to be prioritized by plantation managers. This must be done by

means of avoiding time demanding processes in harvest preparation activities and end of the day activities. Also, attention must be paid to the reasons why strange elements occur, especially those related to minor equipment repair and waiting at the field for inputs or teammates. In this way, effective working times in the assigned tasks will increase for a working day, and labor yields should increase.

A crucial factor determining harvest labor productivity is crop yields. In other words, how many FFB per hectare need to be harvested in a working day. If crop yield is high because of good agronomical crop management, then there will be more FFB to be harvested every time a harvest team enters the same plot. In this case, the costs per hectare of harvest increase, but the costs per FFB ton harvested will decrease. The latter is because a harvest operator will spend more time either cutting FFB or collecting FFB than walking along the fields trying to find FFB to carry out their assigned jobs. Naturally, greater crop yield implicates that areas covered by field operators would be smaller. This conclusion is very important not only for proper crop management but also for scenarios in which FFB production is seasonal. Note that plantation managers tend to define harvest goals in terms of area covered. Our results suggest that one needs to consider crop yield to define the goal in terms of FFB harvested at a working day.

Our discussion focused on comparing harvest labor productivity indicators reported at *E. guineensis* studies and the ones we found at this OxG harvest study. It was observed that despite the morphological differences in OxG hybrid cultivars, harvest teams, harvest tools, harvest equipment, and transport systems used are still the same for both type of cultivars. This may indicate that there is plenty of opportunities to explore OxG crop harvest.

OxG crops requires the development of a set of criteria for the FFB cutters so as to tell if an FFB is at optimal harvest time. Since these criteria are: counting loose fruits, judging for percentages of fruits opacity and judging for percentages of fruits with peel cracking, there is the need to work on developing specific tools for unifying these set of criteria and, that will assist the operators in making quick decisions while in the field.

Acknowledgments

Authors are grateful to Fondo de Fomento Palmero (FFP) which provided the funds to perform this research. The authors are also grateful to the staff from Palmas Monterrey S.A.S for their contribution of human resources and harvest equipment that allow for this research to be undertaken.

Conflicts of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Author contribution statement

“Conceptualization and Methodology, M.M.M.; Investigation, J.E.C.R., S.S.R. and N.F.P.A.; Writing – original draft preparation, J.E.C.R., S.S.R. and E.R.A.; Writing – review and editing, E.R.A., J.E.C.R., and M.M.M.; Funding acquisition, N.F.P. and M.M.M.; Resources, N.F.P.; Supervision, M.M.M.”

References

- Ahmad S, Azman I, Zulhusni A, Nordin A, Salleh KM, Balu N. 2017. Labour productivity of harvesters by country of origin: a case study in peninsular Malaysia. *Oil Palm Ind Econ J* 17: 1–7.
- Caicedo A, Millan E, Ruiz R, Romero HM. 2020. *Criterios de cosecha en cultivares híbrido: características que evalúan el punto óptimo de cosecha en palma de aceite*.
- Camperos JE, Barrera E, Mosquera-Montoya M. 2021. Estudio de tempos e movimentos para mensurar a produtividade da mão de obra nas plantações de palma de azeite de palma na Colômbia: O caso da polinização artificial. *Rev Eletr Compet Digitais Para Agric Famil* 7: 146–171.
- Camperos JE, Pulido N, Munevar DE, Torrecilla E, Requena J, Arias H, Mosquera-Montoya M. 2020. Estudio de tiempos y movimientos para la polinización artificial: estudio de caso en una plantación de la Zona Central. *Revista Palmas* 41: 11–23.
- Colombia BR. 2022. *Boletín de indicadores económicos*. <https://www.banrep.gov.co/economia/pli/bie.pdf>
- Corley RHV, Tinker PB. 2016. *The oil palm*.
- Fairhurst T, Griffiths W, Rankine I. 2019. Oil palm – mature. In: *Oil palm field handbooks* (pp. 243–268). Edit. Tropical Crop Consultants Limited.
- FAOSTAT. 2022. Crops and livestock products – 2019 (Production). In Pagina Web (Accessed 12 sep 2022). [https://www.fao.org/faostat/en/#search/oil palm](https://www.fao.org/faostat/en/#search/oil%20palm)
- Federación Nacional de Cultivadores de Palma de Aceite F. 2021. *Formalización laboral en el sector palmero, un paso hacia la sostenibilidad social*. <https://repositorio.fedepalma.org/handle/123456789/141446#page=1>
- Federación Nacional de Cultivadores de Palma de aceite F. 2022a. Minianuario Estadístico 2022. Principales cifras de la agroindustria de la palma de aceite en Colombia. *Minianuario Estadístico 2022*, 54. <https://repositorio.fedepalma.org/handle/123456789/141446#page=1>
- Federación Nacional de Cultivadores de Palma de Aceite F. 2022b. Anuario estadístico 2022. *Principales cifras de la agroindustria de la palma de aceite en Colombia y en el mundo*.
- Federación Nacional de Cultivadores de Palma de Aceite. 2023. The transforming power of oil palm. Colombian oil palm agroindustry. *Presentation to the Fedepalmás Board of Directors*. November 2023. Bogotá.
- Fontanilla C, Pachón, S., Castiblanco J, Mosquera-Montoya M, Sánchez A. 2010. *Referenciación competitiva a los sistemas de evacuación y alce de fruto*. (Issue 25). <http://hdl.handle.net/20.500.12324/1329>

- Fontanilla C, Alarcón W. 2008. Comparación entre cosecha individual y en grupo en una plantación colombiana de palma de aceite. *Rev Palmas* 29: 11–16.
- Forero D, Hormaza P, Moreno L, Ruiz R. 2012. *Generalidades sobre la morfología y fenología de la palma de aceite*.
- Henson IE. 2012. 5 – Ripening, harvesting, and transport of oil palm bunches. In O. –M. Lai, C. –P. Tan, C. C. Akoh (Eds.), *Palm Oil* (pp. 137–162). AOCS Press. <https://doi.org/10.1016/B978-0-9818936-9-3.50008-3>
- Hernández Rendón DA, Daza ES, Acosta Hernández YA, Mosquera-Montoya M. 2022. Assessing the labor productivity of two methods of artificial pollination in oil palm crops from Colombia. *OCL* 29. <https://doi.org/10.1051/ocl/2022006>
- Ismail A, Mashani S, Sharudin Z. 2015. Labour productivity in the Malaysian oil palm plantation sector. *Oil Palm Ind Econ J* 15: 1–10.
- LMC International Ltd. 2011. *Oilseeds & Oils Report*. <https://www.lmc.co.uk/reports/oilseeds-oils-report/>
- Martínez G, Sarria GA, Torres GA, Varón F. 2010 *Phytophthora palmivora* es el agente causal de la pudrición del cogollo de la palma de aceite. *Revista Palmas* 31(Especial Tomo I): 334–344.
- Mosquera-Montoya M, Camperos JE, Ruiz E, Hernández D, García A, Vargas LE, Mesa E, Munévar D, Sinisterra K. 2023. Evidence of sustainable intensification in the production of palm oil from crops planted with *Elaeis oleifera* x *Elaeis guineensis* in Colombia. *Front Sustain Food Syst* 7: 1217653.
- Mosquera-Montoya M, Ruiz E, Munevar D, Estupiñan M, Guerrero A, Cala S. 2022. Estudio de costos de producción 2021 para empresas benchmark 2021. *Revista Palmas* 43: 26–39.
- Mosquera M, Fontanilla C. 2008. *Estudios de cosecha en palma de aceite*.
- Mosquera M, Fontanilla CA. 2006. Marcación de palmas con racimos maduros: Evaluación de dos metodologías para el proceso de cosecha. *Rev Palmas* 27: 11–25.
- Mozzon M, Foligni R, Mannozi C. 2020. Current knowledge on interspecific hybrid palm oils as food and food ingredient. *Foods* 9: 1–16.
- Munévar M, Daniel E, Ruiz ÁE, Díaz R, William D, Báez C, Diego E, Hernández H, Juan S, Óscar S, Mosquera-Montoya M. 2020. Cosecha en cultivos de palma de aceite mediante el uso del grabber: caso de estudio en una plantación de Colombia. *Revista Palmas. Bogotá (Colombia)* 41: 13–26.
- Navia EA, Ávila RA, Daza EE, Restrepo EF, Romero HM. 2014. Assessment of tolerance to bud rot in oil palm under field conditions. *Eur J Plant Pathol* 140: 711–720.
- Ng YG, Bahri MTS, Syah I, Mori MYI, Hashim Z. 2013. Ergonomics observation: harvesting tasks at oil palm plantation. *J Occupat Health* 55: 405–414.
- Rincón S, Hormaza P, Moreno L, Prada F, Portillo D, García J, Romero HM. 2013. Use of phenological stages of the fruits and physicochemical characteristics of the oil to determine the optimal harvest time of oil palm interspecific OxG hybrid fruits. *Ind Crops Products J* 49: 204–210.
- Romero HM, Daza E, Ayala-Díaz I, Ruiz-Romero R. 2021. High-oleic palm oil (Hopo) production from parthenocarpic fruits in oil palm interspecific hybrids using naphthalene acetic acid. *Agronomy* 11: 1–18.
- Ruiz Álvarez E, Banguera J, Toro WP, Hernández JH, Arévalo J, Montoya MM. 2020. Technical and economic assessment of two harvesting tools for young *Elaeis oleifera* x *E. guineensis* oil palms. *Agron Colomb* 38: 386–396.
- Ruiz E, Mosquera-Montoya M, Munévar DE, Vargas L, Vélez J. 2022. *Productividad laboral en plantaciones de palma de aceite en Colombia de palma de aceite en Colombia* (Issue 43). <https://doi.org/https://doi.org/10.56866/9789588360966>
- Sánchez Á, Edison D, Rodrigo R, Hernán R. 2011. Polinización asistida en palma de aceite. *Tecnologías para la agroindustria de la palma de aceite: guía para facilitadores* (1st ed., Issue 00086).
- Shuib AR, Radzi MKFM, Bakri MAM, Khalid MRM. 2020. Development of a harvesting and transportation machine for oil palm plantations. *J Saudi Soc Agric Sci* 19: 365–373.
- Shuib A, Ramdhan M, Solah M. 2011. Innovation and technologies for oil palm mechanization. Chapter 17 In *Further advances in oil reserach* (2000–2010) (pp. 569–597).
- Torres VM, Rey BL, Gelves RF, Santacruz ALH. 2004. Evaluación del comportamiento de los híbridos interespecíficos *Elaeis oleifera* x *Elaeis guineensis*, en la plantación de Guaicaramo S.A. *Revista Palmas* 25(especial, tomo 2), 350–357.
- United States Department of Agricrop Foreign Agricultural Service, 2022. Oilseeds: World Markets and Trade. USDA Economics, Statistics and Market Information System (Nov 9). <https://usda.library.cornell.edu/concern/publications/tx31qh68h?locale=en>.

Cite this article as: Camperos-Reyes JE, Sánchez-Rodríguez S, Pulido-Álvarez NF, Ruiz-Alvarez E, Mosquera-Montoya M. 2024. Assessing labor productivity in the harvest of crops planted with *Elaeis oleifera* x *Elaeis guineensis* crossings in an oil palm plantation from Colombia. *OCL*, 31: 16