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Prototype of a portable accessory for optimizing coffee harvesting

***Abstract*—Coffee harvesting in Central America faces growing challenges due to labor shortages and the inefficiencies of traditional and semi-mechanized harvesting methods, particularly in mountainous terrain. This project presents the design and field validation of a portable accessory aimed at optimizing the coffee harvesting process by integrating with both manual and semi-mechanized harvesting systems. The proposed solution seeks to reduce bean losses, improve collection times, and eliminate the need for traditional ground nets or 'sarán,' which are often ineffective on irregular land. A functional prototype was developed considering affordability, field adaptability, and ease of transport. Field tests demonstrated a significant improvement in collection efficiency and user experience. This accessory represents a viable, low-cost alternative for small to medium-scale coffee producers, contributing to more sustainable and productive harvesting practices.**

***Index Terms*—Coffee harvesting, portable harvesting accessory, harvesting efficiency, terrain adaptability, field testing**

I. Introduction

Coffee production is a key activity in Honduras, providing income to more than 120,000 farming families across 15 departments of the country. These farming families generated 1.2 million in income from exported coffee during the 2023–2024 harvest cycle [1]. However, it faces significant challenges during the harvest stage, such as labor shortages and inefficiencies of traditional methods in difficult terrains. For this reason, this project was developed on a coffee farm, aiming to design an accessory that speeds up manual harvesting or semi-mechanized coffee harvesting, making the pickers' work easier and reducing losses from cherries falling outside the collection area. This innovation seeks to offer a more efficient and accessible solution than conventional tarps used in the semi-mechanized coffee harvesting, adaptable to various types of terrain, and thus contribute to improving the productivity and competitiveness of the Honduran coffee sector.

II. Objectives

A. General Objective

- Develop a coffee harvesting device that is cost-effective for coffee producers as an alternative to the use of tarps, accelerating the harvesting process, optimizing collection times on farms, and reducing product losses caused by mountainous terrain.

B. Specific Objectives

- Define the characteristics the device must have for use by coffee pickers on farms, using easily accessible materials that ensure functionality.
- Design the device to work efficiently on farms with mountainous terrain, ensuring it effectively captures the coffee and transfers it to the collection containers.
- Analyze the performance of the device by comparing the speed and accuracy of coffee harvesting against traditional methods such as manual harvesting.

III. State of the Art

To develop this prototype, a literature review was conducted on current technologies used in coffee harvesting and the characteristics of Honduran farms, establishing a technical foundation for the prototype's design.

A. Topography of Coffee Cultivation in Honduras

The topography of coffee cultivation in Honduras is mostly mountainous, which presents challenges for achieving a successful harvest. The most productive departments—such as Santa Bárbara, Copán, and Lempira—feature steep slopes and volcanic soils shown in "Fig. 1", conditions particularly favorable for growing high-quality coffee [2].

Fig. 1. Coffee plantation in Copan

These areas not only complicate mechanization due to their rugged terrain but also require specialized management techniques to optimize production and preserve soil and environmental integrity [3]. Despite these challenges, the unique topographic environment greatly contributes to the originality and international reputation of Honduran coffee.

B. Harvesting Processes

There are different types of processes and tools used for harvesting. The most common are manual "Fig. 2" and assisted harvesting "Fig. 3". Manual harvesting involves detaching the fruit and letting it fall freely onto tarps, with this being the only required micro movement [4].

Assisted coffee harvesting is a concept aimed at improving the profitability of coffee farming by increasing labor productivity in harvesting through the use of various machines for detaching the fruit [5].

Fig. 2. Manual coffee harvesting

Fig. 3. Assisted coffee harvesting

C. Coffee Harvesting Tools

The development of tools to facilitate and accelerate the coffee harvesting process has been on the rise, as the need for such instruments has become a priority. These tools are generally categorized into three groups: mechanized tools, which collect a large amount of coffee with minimal operator involvement; semi-mechanized tools, which require some operator intervention; and manual-assisted tools, which rely entirely on the operator, who manually detaches the cherries [6]. Reference [7] developed the Selective Coffee Harvester DSC18, which uses a vibration mechanism to selectively detach ripe coffee cherries. In evaluated studies, the machine was found to increase harvesting efficiency by 180 percent compared to traditional manual methods. Reference [8] also developed a tool called zaranda, used during the harvesting process. This tool operates on the principle of separation, distinguishing between fruits, leaves, and stems based on size differences.

D. Assisted Harvesting

7
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The concept of Assisted Harvesting in coffee collection involves adopting three practices that can be used additively and scaled regardless of farm size: pass retention, harvesting with tarps "Fig. 4", and the use of fruit-stripping machines such as the DSC18 [9]. The Brudden DSC18 coffee stripper, used in assisted coffee harvesting, utilizes branches to transmit vibrations and cause the cherries to fall by peduncle fatigue [10]. This machine must be used in conjunction with pass retention and tarps to collect the fallen fruit. From the perspective of the coffee grower, this method involves additional costs for tarps, including purchasing, maintenance, and storage [11]. Literature on this topic also discusses harvesting performance, the amount of green fruit collected, ripe fruit left unharvested, and fruit fallen to the ground.

Fig. 4. Brudden DSC18 coffee stripper with the use of tarps

E. Coffee Harvesting Labor

One of the main structural issues faced by the coffee sector is the shortage of labor for harvesting and its impact on production costs [12]. Migration patterns are interrelated, affecting both the demand for local labor and the migration of workers to other regions [13]. The National Coffee Council emphasized the need to prioritize new research in coffee harvesting and the development of technologies that can supplement and optimize labor during the harvest, given the significant role this activity plays in production costs. Alongside the labor shortage in the country, many coffee producers nationwide have opted to switch to other crops or abandon the coffee sector altogether [14].

F. Plantation Density

Coffee production per area increases as the number of plants grows; however, conversely, the production per coffee plant decreases as plant population increases [15] . In general, a density of 5,000 plants per hectare can be established, with a spacing of 2.0 meters between rows and 1.0 meter between plants, as indicated by [16].

TABLE I
SPACING OF THE MOST COMMONLY USED COMMERCIAL VARIETIES IN HONDURAS

Coffee Variety	Distance Between Plants	Distance Between Rows
Caturra/Paca	1 m	2 m
Catuai/IHCAFE-90	1.25 m	2 m
Lempira	1 m	2 m
Typica/Bourbón	1.25 m	2.2 m

G. Field Test

Field tests are experiments conducted outside of laboratory settings. These tests require researchers to maintain control over randomization and implementation and allow for the collection of various types and amounts of data [17]. The field test will help us verify that the accessory fulfills its intended function, assess ease of use, and determine whether it truly saves time and effort in the coffee harvesting process.

IV. METHODOLOGY

This research project is designed under a mixed experimental approach, combining both quantitative and qualitative methods, as this combination allows for a comprehensive evaluation of the efficiency and ease of use of the developed harvesting accessory. To ensure proper development of the coffee harvesting accessory, bibliographic research was conducted, consulting various sources about the current state of coffee production in Honduras and in coffee-growing regions.

Additionally, issues related to coffee loss during harvesting on uneven terrain were identified, and harvesting technologies used in plantations with similar characteristics to coffee were analyzed. Research was conducted on the characteristics of coffee farms, and the aspects that could limit the design conditions were analyzed. Some of these included irregular terrain topography, planting density, and the typical tree sizes of the most popular coffee varieties in Honduras. This research was essential, as the design criteria for the accessory were determined based on these findings.

Since one of the design conditions was the irregular topography of coffee farms, the harvesting accessory was designed with a base capable of being adjusted at its four support points, to ensure stability by adapting each point as needed. Likewise, planting density imposed other design conditions, as the accessory had to be smaller than the distance between plants. For this reason, a canopy opening and closing system was designed for the harvesting accessory. With this design, the accessory can better adapt to denser farms, where the space available to walk between plants is more limited. Additionally, the canopy's opening and closing system was designed with the variability in coffee plant size in mind, allowing the accessory to function regardless of the plant's height and shape.

After the accessory was designed to meet the initial requirements, the mechanisms were developed to enable the opening and closing functionality of the harvesting canopy. Subsequently, the most suitable materials were researched, considering the final weight of the accessory and its durability. Finally, a frame was built for the mechanisms, which would serve as the base for the canopy structure and the adjustable supports.

The field test was carried out on two productive farms with characteristics similar to those studied. The stability of the accessory was tested on uneven terrain by individually adjusting the four support points to compensate for ground variations. The functionality of the canopy's opening and closing system, as well as its adaptability to the different plant sizes encountered, was tested by adjusting the opening and closing mechanism to adapt the accessory to the various characteristics of the plantation. Detailed data were recorded, including the time required for each adjustment, productivity, fruit losses, the stability of the accessory under different conditions, and the response of the opening mechanism based on the variability in the size and shape of the plants. The collected information was organized into tables and graphs that allowed for a comparison of the accessory's performance in different scenarios with traditional methods. To analyze the ease of use of the accessory, a qualitative analysis was conducted based on the observations and opinions of the harvester and producer through a survey.

A. Variables

1) Independent Variables:

- Canopy Design: The canopy must be made of a lightweight and durable material that does not affect the quality of the coffee. Its design should facilitate the movement of the cherries towards a strategically placed opening, due to the inclination and low friction of the canopy. The purpose of the opening is for the harvester to place a container directly underneath, making the collection easier and faster.
- Structure Design: The design of the structure is based on its ability to provide support, stability, and adaptability to the harvesting accessory while in operation on different types of terrain and coffee plantations. The structure must be durable to protect the internal mechanisms and support the weight of the coffee, while also being lightweight to facilitate handling and transport.
- Mechanisms: The design includes systems for opening and closing the harvesting accessory, which involve the use of components such as hand cranks, pillow blocks, straight gears, bevel gears, racks, and bearings, all designed and installed to ensure efficient and continuous movement.
- Materials: The materials were selected to ensure the efficiency and durability of the accessory. The materials must be lightweight to facilitate use, durable due to the climatic conditions to which it will be exposed, non-abrasive to prevent damage to the fruit, and cost-effective to keep manufacturing costs low, making the product affordable for the producer.

2) Dependent Variables:

- Collection Time: Comparison of the time required to harvest a specific amount of coffee using the accessory versus the traditional method (min/lb harvested).

- Productivity: Evaluation of the accessory's performance in terms of the amount of coffee harvested within a specified time (lb/hour of work).
- Coffee Losses: Percentage of coffee cherries not harvested due to falling outside the harvesting accessory.
- Ease of Use: Perception of the harvesters regarding the comfort and efficiency of the accessory through field tests.

B. Materials

- Gears and rack made of PETG
- Aluminum tubes
- Bearings

V. Results

A. Prototype construction

The design was made in SolidWorks, illustration 5 shows how a crank was developed to adjust the opening and closing system and how the rack and pinion mechanisms work in it.

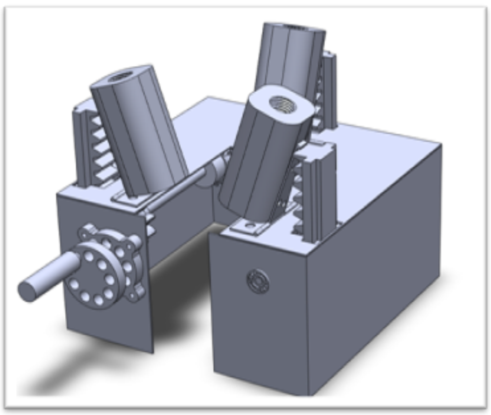

Fig. 5. Opening and closing system design

Fig. 6. Prototype before mounting

B. Field test

The field test was carried out at the coffee farm "Cual Bicicleta" owned by Oscar Omar Alonzo, located in the village of El Trapiche, municipality of Chinacla, La Paz, on Saturday, March 15, 2024. The farm in question is located at 1550 meters above sea level, and by that date, it was already in its final harvest. This farm met the characteristics needed to evaluate the performance of the accessory on uneven terrain and in areas with high plant density. The team traveled to the site, and trees were randomly selected to conduct the tests.

Fig. 7. Field test

C. Data analysis

To evaluate the performance of the harvesting accessory, the installation time of the equipment was recorded. This installation time was divided into four well-defined stages. First, the bases are adjusted to ensure the accessory has good stability. Then, the supports for the collecting net are attached, followed by securing the net onto the supports to ensure most of the harvest from the tree falls onto the mesh. Finally, the hose is fixed in place to redirect the coffee cherries into the sacks.

To complement the analysis, Illustration 6 helps identify the stages that require the most time from the harvesters when using the harvesting accessory. It is observed that the placement of the canopy represents the longest stage in the installation process, while attaching the hose and the canopy supports were the quickest and most consistent. The total installation time tends to decrease, indicating improved operational efficiency as users become more familiar with the accessory. The average overall performance of manual harvesting using the fabricated collection accessory was 29.75 lb / h per harvester. However, the collection accessory shows

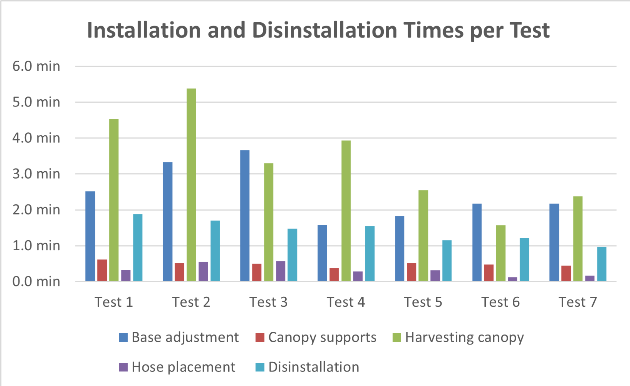

Fig. 8. Installation and Disinstallation Times per Test

a high standard deviation, which can be explained by the fact that the use and adoption of the equipment is still a learning process. The trend line indicates a steady increase in the performance of the accessory as more tests are conducted, suggesting that the accessory becomes more effective as the harvesters improve their technique over time. To compare the

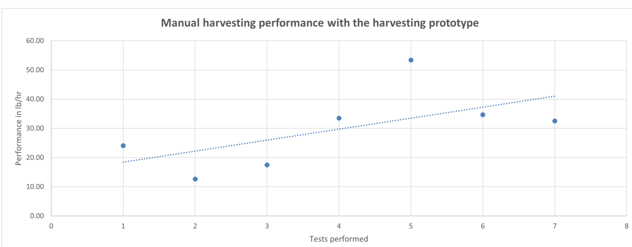

Fig. 9. Manual harvesting performance with the harvesting prototype

performance with respect to the traditional method, data from current harvests (2024-2025) from three different farms were used as reference. These farms had average yields of 17.32 lb/hr (Finca La Colmena), 18.20 lb/hr (Finca El Maná), and 10.14 lb/hr (Finca Vishnu) at a rate of 6 working hours per day. The accessory showed an increase in performance of up to 2.9 times faster than the traditional manual harvesting method at Finca Vishnu.

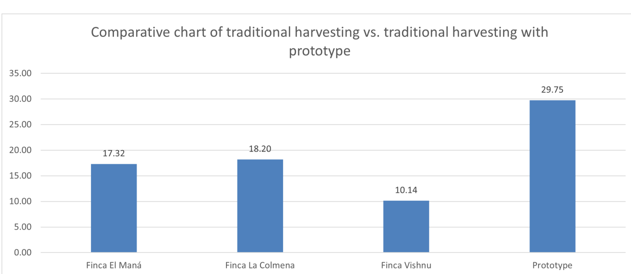

Fig. 10. Comparative chart of traditional harvesting vs. traditional harvesting with prototype

VI. Conclusions

At the end of this project, a coffee harvesting device was successfully developed. It was shown to be functional, streamlining the harvesting process, optimizing collection times on the farm, and reducing losses caused by mountainous terrain, thus fulfilling the main objective of this work. The following key conclusions were drawn:

- The characteristics that the equipment needed to meet were correctly defined based on the conditions found on the farms, using easily accessible materials that ensured its functionality. The structure remained stable, even on uneven terrain, and the design was positively evaluated by the harvesters.
- A functional device was designed to operate on farms with uneven terrain, which was able to adapt to the different slopes of the land. The canopy opening and closing system was effective during the tests.
- The performance of the equipment was analyzed compared to traditional methods, with quantitative measurements taken. The process was observed to be faster and less physically demanding. Harvesters reported an improvement in work comfort.

VII. Recommendations

Based on the project's results, for further investigation, we have some recommendations.

- Redesign the harvesting canopy by increasing its dimensions to ensure a better fit with less tension on the supports. This aims to facilitate and reduce installation times. Additionally, it is considered that a two-piece canopy could work better, especially on farms with high tree density and limited space between plants or on very leafy trees.
- Replace the use of screws for securing the adjustable bases with spring button clips commonly used in tents, and replace the use of a rope for securing the hose with plastic ties or Velcro. This would speed up the installation process.
- Finally, this recommendation involves reorganizing the angular distribution of the canopy supports to an equal separation of 120° between them. Another option is to add a fourth support with a 90° separation, with the aim of achieving better centering of the accessory under the tree and a more uniform harvesting cone.

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