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Performance Evaluation, Machine Parameters and Ergonomic Aspects of Palm Fruit Harvesters

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ABSTRACT

Oil palm fruit is an essential product derived from the palm trees. The stress associated with palm fruit harvesting, particularly from tall palm trees, supports the call for a technology transition from manual to mechanical harvesters. The study's objective is to evaluate the performance and also determine the machine parameters and ergonomics of the oil palm harvester to aid in adopting the machine, training farmers, and addressing operator inefficiencies. The study was conducted using a cross-sectional survey involving 261 farmers, an observational, experimental, and evaluative approach through multiple testing procedures based on the ground theory. The study assesses oil palm harvesting practices, highlighting the prevalence of sickle-pole harvesters (76%), despite ergonomic challenges causing operator fatigue and health risks. Mechanical harvester adoption is limited (3%) due to high costs and availability, compared to manual harvesters. Performance evaluation reveals a reduction in the expected improvement in the mechanical harvester's capacity by 65 fresh fruit bunches (FFB), mainly attributed to operator inefficiencies, yet it proves 22 % more efficient than manual methods (P-value of 0.8287 was obtained under 5 % significance level). A predictive model underscores the mechanical harvester's potential, hindered by persistent low adoption due to cost considerations. The study addresses ergonomic concerns, proposing modifications for vibration-induced fatigue. Emphasizing the need for stakeholder engagement and policies to promote mechanized agriculture in Ghana, the research contributes valuable insights to precision agriculture and ergonomic design.

1. Introduction

Oil palm, produced on 0.36% of the world's agricultural land, constituted 34% of the world's vegetable oil in 2017 [1]. The global demand for palm oil was estimated in 2019 to be 74.6 million tonnes and has been forecasted to obtain a volume-based Compound Annual Growth Rate of 2.3% from 2020 to 2027. The increasing demand for the commodity is due to its economic value as an

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industrial raw material in food and beverages, personal care and cosmetics, biofuel, energy, and pharmaceuticals [2, 3].

According to Talib and Darawi [4], the increasing demand for oil palm in the industry causes large-scale production in which the harvesting phase is one of the most tedious and constitutes the most critical phase of the oil palm production chain. The demand for oil palm and its tedious harvesting phase has advocated the use of mechanical technology to replace manual harvesting, although it has cost implications [5]. The technology has transitioned rapidly from manual cutting tools to mechanical harvesters, vacuum-cutters, and climbing robots to reduce the harvesting duration and losses and to maintain and optimize the quality of fresh fruit bunches (FFB) [6, 7]. Mechanizing oil palm harvesting involves using machines to perform harvesting more straightforwardly and uncomplicatedly [8]. This technology reduces the number and cost of labor and increases workers' output. Whereas drudgery is minimized, harvesting time is diminished for optimum work [9, 10, 22]. The performance of the mechanical harvester is influenced by its machine parameters, thus, causing skepticism in researchers to identify and verify these specifications and establish their interrelationships as well as how they influence the performance of the mechanical oil palm harvester. This will contribute to existing knowledge and establish a theoretical framework for future studies.

Upon thorough assessment and evaluation, the mechanized harvester can become the primary mechanism for harvesting FFB because manual harvesting is more tedious, especially in the African agricultural landscape where mechanized agriculture is gaining traction. Ergonomics of the mechanical harvester is a pre-consideration in assessing the machine's performance but the literature needs more data [14]. This study contributes to knowledge and fills the research gap in this discipline. In Ghana, farmers get curious after using the mechanical harvester, whose utility, to some extent, depends on the machine's ergonomics [15, 16].

Ergonomics involves assessing the adaptation of the machine operator to the harvesting equipment. Machine operators are the sole determinants of the level of fatigue and comfort involved in using the machine and the ease of use [17]. In ergonomic assessment, one objective is to guarantee harmonious working conditions in all worker activities [18]. However, its accomplishment is challenging due to the difficulty in adapting to it, since it is a perpetual learning process, although there may be individual variations in skills, strength, etc. [10, 17]. For this study, the mechanical harvester’s ergonomics considers factors such as length, orientation, adjustment, machine weight, the height of palm trees, and operators' experiences. These considerations are not selected in isolation but rather based on the principle of engineering design as proposed by Mohan and Patel, Tumit *et al*., Thota *et al*., [18-20].

This study seeks to make significant contributions to address two primary research questions: What are the performance indicators and parameters evident for mechanizing or not mechanizing palm fruit harvesting in Ghana? And what are the ergonomic aspects that enable operators to adapt to mechanical harvesters?

Unlike this study, previous studies failed to establish the machine parameters and ergonomics of the oil palm harvesting machine and how they influence the overall performance of the machine. The essence of this work is to contribute to knowledge and to serve as a reference for relevant stakeholders such as Engineers, technologists, etc. to improve the design of the machine and to make it more ergonomically friendly for optimum returns. Generally, the study seeks to achieve the following objectives. First, to evaluate the performance of the mechanical palm fruit harvester and compare it with the existing manual harvesters. Second, to determine the machine parameters of the mechanical harvester and how they influence its performance. Third, to determine the ergonomic parameters of the machine and assess their effect on the output of the mechanical harvester.

2. Methodology

2.1 Study Area

The study was carried out in Kwaebibirem Municipal in the Eastern Region of Ghana. The Eastern region is known in Ghana to be one of the epicentres of oil palm with the largest oil palm processing plant in the country. Figure 1 shows a map of the study area. Spatial maps of palm plantations were generated using ArcGIS version 10.2 for the communities within the Kwaebibirem Municipal where all the data relevant to this study were obtained. Data obtained from the Ghana Oil Palm Development Company showed that the Kwaebibirem Municipal is the leading producer of oil palm in Ghana and that aided in selecting Kwaebibirem as the study area for this research.

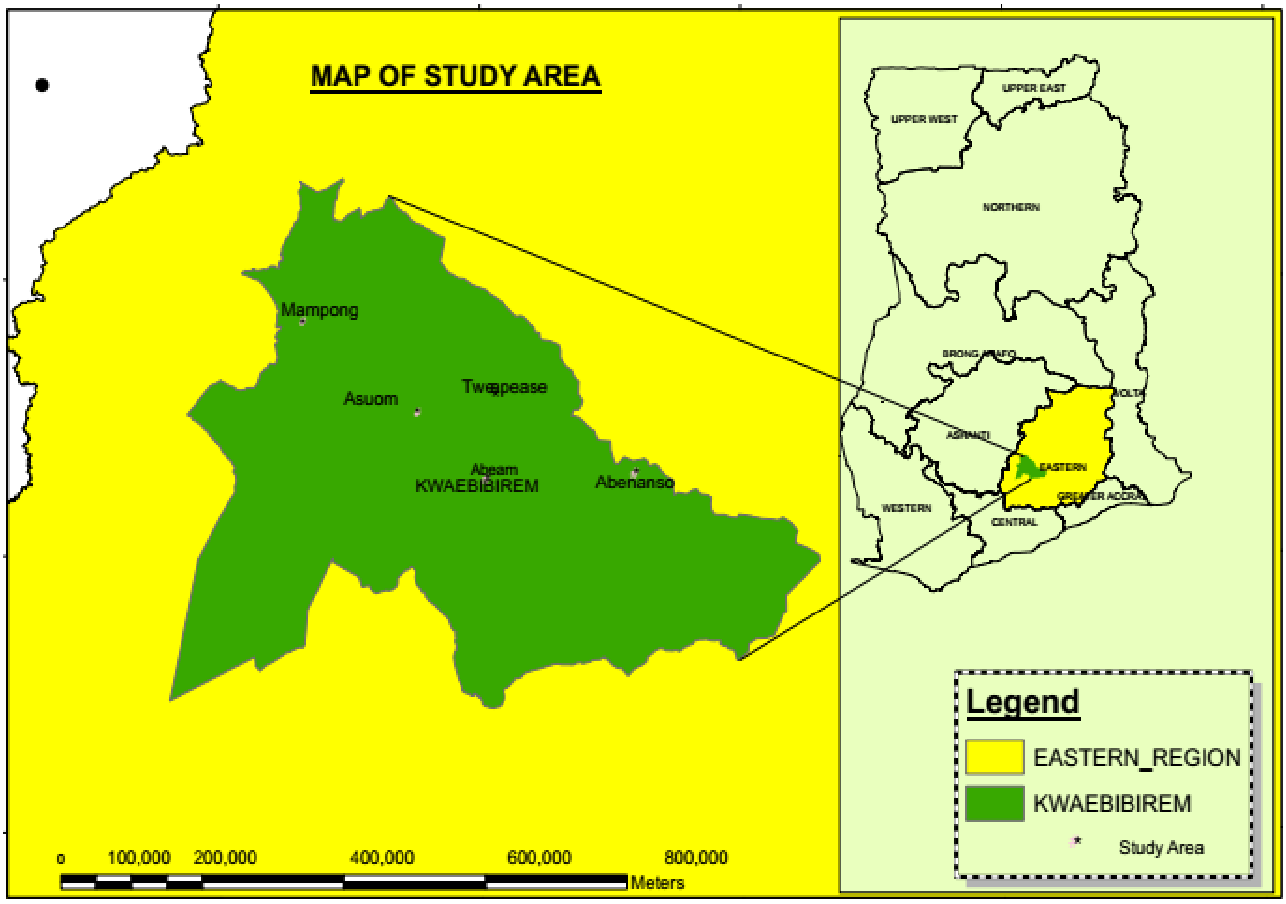

Fig. 1. Map of the study area

2.2 Study Approach

A cross-sectional survey was conducted and survey questionnaires were administered to a sample of 261 farmers and harvesting equipment operators from the communities illustrated in Figure 1. The machine was dismantled and thoroughly studied to ascertain its mechanism and principle of operation and reassembled after all machine parameters required for this study were measured using the measuring instruments presented in Table 1. Afterward, the harvesting experiment was undertaken to assess the performance of the manual and mechanical harvesters. During the experiment, the capacity and harvesting time were measured for each equipment for comparison. The ergonomic parameters such as the tree height, pole length, range of pole adjustment, and pole inclination were all measured for analysis and establishment of their influence on oil palm harvesting. The data collected was analyzed, interpreted, and discussed as per the theoretical framework of the study.

2.2.1 Cross-sectional survey and sampling procedure

Cross-sectional survey questionnaires were administered to 261 farmers. The purpose was to gather relevant data for assessing the types of palm fruit harvesters; evaluate the performance of the mechanical harvester in comparison with the manual harvester; determine the machine parameters and aspects of ergonomics of the mechanical harvester to generate data for product improvement. The sample size was determined based on the total number of farmers in the Kwaebibirem Municipal through a simple random sampling technique. The sample size was determined according to Eq. (1).

$$n = \frac{N}{1 + N(\alpha^2)} \quad (1)$$

where n = sample size, N = total population (751 according to data from the Ghana Oil Palm Development Company, GOPDC), and $\alpha =$ significance level (0.05).

2.2.2 Manual harvesting

A team of four workers was formed to undertake an experiment on the use of the existing manual harvesters (sickle-pole). Two of the team members were responsible for cutting the palm fronds and fresh fruit bunches (FFB) as shown in Figure 6 (a), while the remaining two were responsible for the collection of loose fruits and stacking of palm fronds and bunches, just to clear the walkway and to make the counting of FFBs easier and faster. In line with the scope of the study at this stage, the required activity for this experiment is the use of this manual harvester to cut (harvest) FFB, hence no particular significance is placed on the involvement of the frond and palm fruit collectors since their involvement will not influence the needed data for the scope of this study.

2.2.3 Mechanical harvesting

A team of three workers was formed to undertake the field trial of the mechanical oil palm harvesters. One of the team members was responsible for only the cutting operation of the palm fronds and the fruit bunches as shown in Figure 6 (b) whereas the others were responsible for loose fruit collection, palm fronds stacking as well as stacking the bunches at a central point for the onward transition to the processing centre. In line with the scope of the study at this stage, the required activity for this experiment is the use of this mechanical harvester to cut (harvest) FFB, hence no particular significance is placed on the involvement of the frond and palm fruit collectors since their involvement will not influence the needed data for the scope of this study.

This mechanical oil palm harvester was selected for the study because the sophistry of the machine design is comprehensible allowing for easy repair and maintenance. The only alternatives to this equipment in the Ghanaian agricultural sector is the sickle-pole harvester at the time of this experiment.

2.2.4 Measurement of physical quantities and variables

A pre-study was conducted by selecting at random, two plantations in Asuom and its adjoining communities to pilot the performance of the mechanical harvester. The main study was conducted in Kwaebibirem where five different plantations of average tree height of 4.8 m were randomly selected for harvesting. The five plantations were selected from the communities of Twapease, Abaam, Mampong, Asuom, and Abenanso. Skilled operatives, who had a minimum 12 months experience in oil palm harvesting and were within the ages of 20-40 years were randomly selected among the residents of the Asuom and the adjoining communities. These criteria were used to ensure the sampling of operative with the skill and physical strength to execute the task. Variables that were measured during the harvesting process were machine capacity, duration of harvest, operating speed of the machine, and ergonomic considerations (machine inclination, length, weight, and the range of pole adjustment of the mechanical harvester). Table 1 illustrates the instruments that were used to measure the parameters indicated against them.

Table 1
Measuring instruments used for the study

SN:	Measuring Tools	Function
1	Stopwatch	Time
2	Digital tachometer	Engine speed
3	Weighing scale	Mass
4	Surveyors tape	Length of pole and tree height
5	Vernier calipers	Smaller diameters and thickness (eg. bunch stalk diameter, etc.
6	Steel rule	Short lengths (eg. Length of blade, dimensions of palm fronds, etc)

2.2.5 Theoretical framework

The theory that anchors the study is the grounded theory, a qualitative research approach that systematically generates theory from available data. The study employed this theory through experimental and observational approaches, unlike previous studies that adopted established alternatives. The research method is summarized in the flow chat illustrated in Figure 2.

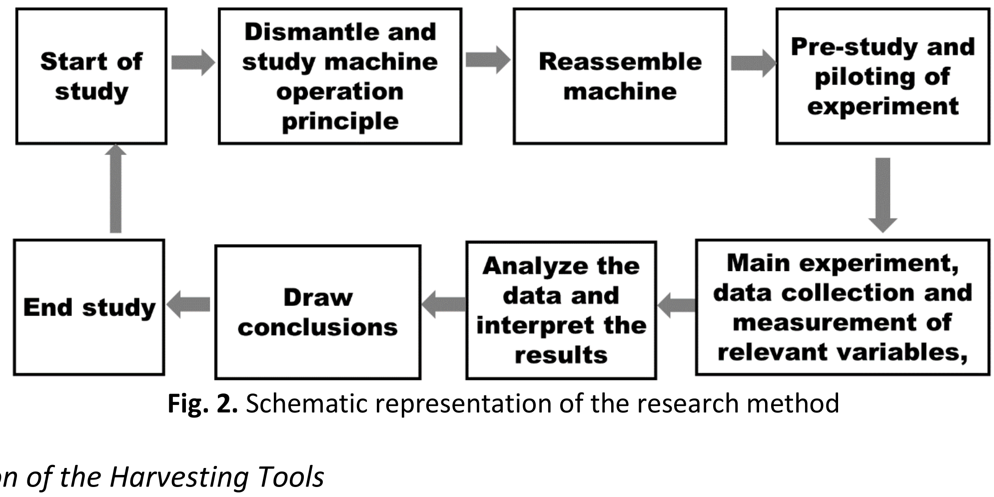

Fig. 2. Schematic representation of the research method

2.3 Selection of the Harvesting Tools

Manual and mechanical harvesters (Figure 3-5) were used for the experiment. The manual harvester was made up of a sickle and pole fastened together. The mechanical harvester consisted five major components, including a prime mover, telescopic pole, transmission shaft, speed converter (slider-crank mechanism), and cutter. This mechanical oil palm harvester was selected for the study due to the simplicity of the machine design and resource availability for repair and maintenance. At the time of conducting this study, there were no mechanical alternatives to this equipment in the Ghanaian agricultural landscape. Tables 2 and Table 3 represent the dimensions of the tools selected and the part list of the mechanical harvester respectively.

Table 2
Length and mass of the manual sickle-pole and mechanical harvesters

Quantity	Sickle-pole harvester	Mechanical harvester
Length (m)	3.4	5.2
Mass (kg)	1.8	9

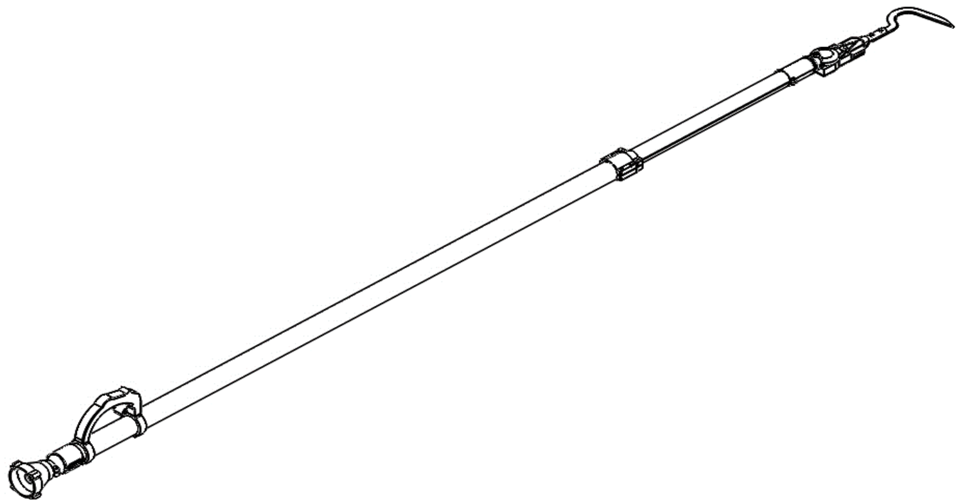

Fig. 3. Pictorial view of the mechanical oil palm harvester

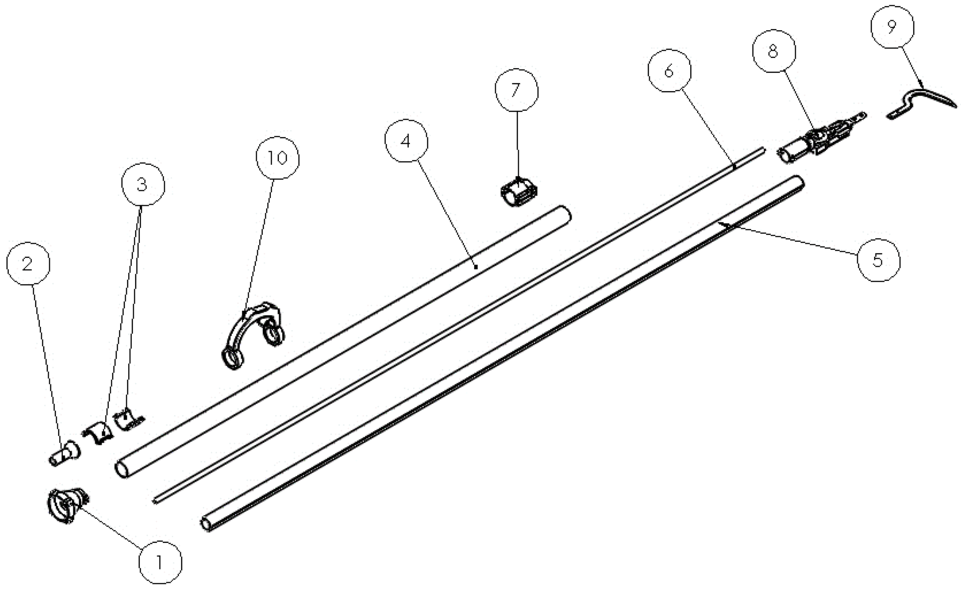

Fig. 4. Exploded View of the Mechanical Oil Palm Harvester

Table 3
Parts list of the mechanical harvester

Part number	Part name	Q'ty
1	Engine holder	1
2	Shaft seat	1
3	Cover	1
4	Outer shaft	1
5	Inner shaft	1
6	Transmission shaft	1
7	Holding plate	1
8	Cutting head	1
9	Cutting blade	1
10	Handle	1

Fig. 5. Picture of the 1.3 Hp gasoline engine (2-stroke) of the mechanical harvester

(a) (b)

Fig. 6. (a) Manual harvesting and (b) Mechanical harvesting of palm fruits

2.4 Theoretical Considerations
2.4.1 Machine parameters

The cutting force and operating torque of the mechanical harvester were computed using Eq. (2) and Eq. (3). Other machine parameters determined were speed, range of pole adjustment, mass, capacity, and length.

$$Cutting\ Force, F_c = \frac{m_b v}{t} \tag{2}$$

where
$F_c =$ Cutting force (N)
m_b= Mass of cutting blade (kg)
$t =$ Average time taken to cut a bunch/ frond (sec)
$v =$ Linear velocity of cutting blade (ms^{-1})

$$Operating\ Torque\ T_o = F_c s \tag{3}$$

where:
$T_o =$ The operating torque of the machine
$s =$ The perpendicular distance (m) between the axis of rotation of the shaft and the point of action of the cutting force.

2.4.2 Ergonomic assessment

The ergonomics assessed the ease of use, and the machine's ability to provide comfort and cause minimum fatigue. The ergonomic considerations for this study included the tree height, arm reach of the machine operator, inclination of the machine pole, machine weight, and vibration. Pole length, tree height and distance between the machine operator and the palm tree were measured using surveyor's tape. Pythagoras theorem was used to determine the inclination.

2.4.3 Hypothesis testing

It is generally claimed by mechanical (motorized) harvester manufacturers that their products have a mean daily capacity of more than 560 free fruit bunches (FFB) in line with study outcomes presented by Abdul *et al*.; Zahid-Muhamad and Aziz,; Azman *et al*., [6, 8, 15]. A random sample of 5 harvesting days was taken and the mean daily capacity and a sample standard deviation were determined. To test the hypothesis, there was the need to formulate the null (H_0) and alternative (H_a) hypotheses as indicated below:

i. H_0: the mean daily capacity of the mechanized oil palm harvesters is not more than 560.

ii. H_a: the mean daily capacity of the mechanized oil palm harvesters is more than 560.

A mathematical expression for the null and alternative hypotheses is indicated in Eq. (4).

$$H_0: \mu \leq 560$$
$$H_a: \mu > 560 \tag{4}$$

where μ is the population Mean. This hypothesis represented in the inequalities above was tested by calculating the (test statistic) t-test value and the critical sample mean as given by Eq. (5) and Eq. (7) below; [22]. The t-test is a statistical test that compares the means of two groups to ascertain whether they are different from each other or a process has an influence on the population of interest.

$$t_x = \frac{\bar{x} - \mu}{\sigma_{\bar{x}}} \tag{5}$$

$$\sigma_{\bar{x}} = \frac{s}{\sqrt{n}} \tag{6}$$

$$\bar{x}_c = \mu + t_c \sigma_{\bar{x}} \tag{7}$$

where t_x is the test statistic, $\bar{x}$ is the sample mean, μ is the population mean, $\sigma_{\bar{x}}$ is the sample standard error, s is the sample standard deviation and n is the sample size.

2.5 Limitations of the Study

Few respondents to the survey questionnaires needed to be guided before they could accurately provide some of the responses to the questions. Not only that but also the tree height, could not be measured directly unless a wooden pole was initially used to mark the tree height before directly measuring it using the surveyor's tape. Again, parameters such as the angle of harvesting equipment pole inclination, cross-sectional area of palm frond (cut surface) and bunch stalk required arithmetic computation.

2.6 Data Analysis

Data collected from the field were analyzed using the statistical analysis tool pack in Microsoft Excel at a 5 % significance level using multiple testing approaches.

3. Results

3.1 Palm Fruit Harvesting Equipment

The results of the survey conducted for this study revealed that the age distribution of 261 sampled oil palm plantation operators ranged between 20-91 years as shown in Figure 7, with 27 % female involvement. Some participants owned plantations (55 %), others were equipment operators or labourers, who specialized in oil palm harvesting (31 %), whereas 14 % of the participants owned plantations and harvested their produce by themselves.

Also, 76% of the oil palm farmers used sickle-pole harvesters for harvesting palm fruits although it was noted that the upper body of the operator of this equipment experienced awkward postures while performing the harvesting tasks, which led to muscle fatigue. The implication is that the use of the manual harvest does not only involve drudgery, it poses severe health risks to operators, which is consistent with the findings of Saibani *et al*.; Deros *et al*., Fadzil and Tamrin, [11-13, 38]. Also, 21% used chisel-pole harvesters and machetes, while only 3% used mechanical harvesters. Sickle-pole, chisel-pole harvesters, and machetes can be accessed locally, whereas mechanical harvesters are usually imported. Therefore, mechanical harvesters are purchased at a relatively high cost from equipment suppliers in the cities, in line with the conclusion of Ruiz *et al*., [40]. Higher prices of mechanical harvesters are due to factors such as rising import duty, rise in the exchange rates, high cost of individual replacement components, and shortage in supply. These have caused an estimated increase in prices of new farm machinery and equipment by 240 % within the last two years in Ghana. This diverges from the conclusion of Fritz *et al*., [24] who estimated a 4 % per annum rise in the prices of new farm machinery and equipment for at least the past decade.

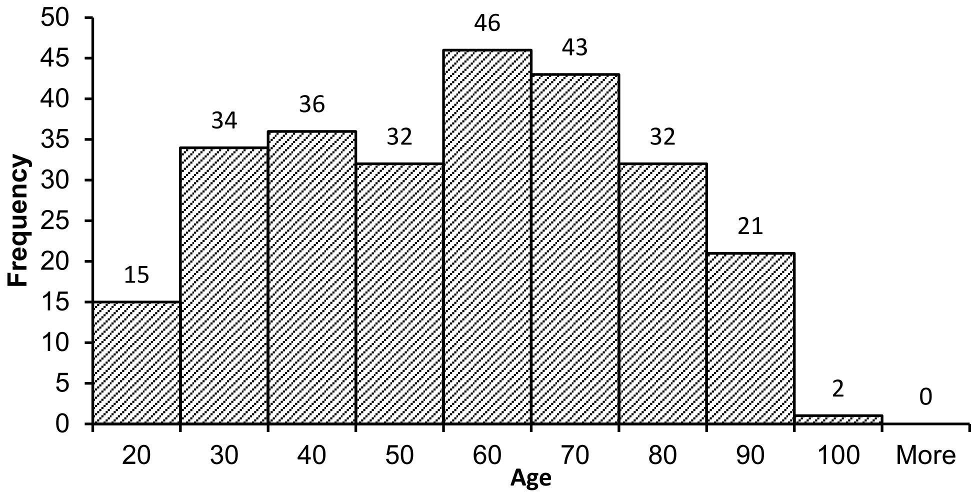

Fig. 7. Age distribution of farmers in Kwaebibirem

3.2 Principle of Operation of the Harvesting Equipment

The manual harvester comprises a locally made sickle and a hollow aluminium pole reinforced with wood in multiple pieces to allow for adjustment of its length. The sickle is fastened to the pole by a pin and tied with an elastic rope or rubber band. Harvesting is done by manually pulling the fronds or bunches with the sickle of the equipment for cutting. If the palm tree is taller than the length of the pole, the operator increases the length of the pole by adding more pieces of the wood-reinforced aluminium pole as illustrated in Figure 6 (a).

The mechanical harvester pictorially shown in Figure 3 and exploded in Figure 4 is made up of five major components; the prime mover, power transmission shaft, operating mechanism, cutting blade, and telescopic pole. The prime mover is a 1.3 hp, 2-stroke gasoline engine that produces power for use in cutting FFB and palm fronds as shown in Figure 5. The power is transmitted to the cutting blade through the power transmission shaft in Figure 4 (part number: 6). The rotational speed of the transmission shaft serves as an input to the operating mechanism in Figure 4 (part number: 8), where a bevel-spur gear train and a bearing forming a slider-crank mechanism converts the rotational speed into linear reciprocating motion to drive the sickle, hence causing this to-and-fro motion of the sickle to cut palm fronds and FFB. The machine operator applies minimal efforts to guide the blade through the fronds or the stalk of the FFB as illustrated in Figure 6 (b), unlike the manual harvester, where cutting is achieved solely through physical effort.

3.3 Performance of the Harvesting Equipment

Table 4 illustrates the average daily capacity, and cutting time for the sickle-pole and mechanical harvester. The key determinants of the performance of the harvesting equipment are capacity and cutting time. The results revealed that the harvesting machine has an average capacity of 239 FFB/day and that for the sickle-pole harvester is 192 FFB/day. This is similar to the results obtained by Abdul *et al*., [6], which were 498-561 FFB for the mechanical harvester and 214–238 FFB for the manual harvester. The implication is that farmers are unfamiliar with, and do not have adequate skills to use the mechanical oil palm harvester as a result of non-availability and lack of training. It also implies that although the performance of the mechanical harvester is higher than the sickle-pole, the data suggest a drastic reduction in the capacity of the mechanical harvester by 43-48 % contrary to the expected improvement suggested by Mohamaddan *et al*., Ruiz *et al*., [37, 40]. This is attributed to nonfamiliarity on the part of operators. The significance of this result is that it is a call for stakeholder engagement to develop and implement policies that motivate farmers to embrace and adopt mechanized agriculture in the Ghanaian agricultural landscape.

Table 4
Daily capacities of manual and mechanical palm harvesters

Day	Mechanized			Manual		
	No: FFB harvested	Duration (hr)		No: FFB harvested	Duration (hr)	
		Total	Effective		Total	Effective
1	213	8	6.32	203	8	3.97
2	239	8	6.01	198	8	5.55
3	264	8	6.22	202	8	4.67
4	219	8	6.24	167	8	4.59
5	258	8	6.31	189	8	4.57
Sum	1193	40	31.1	959	40	23.35
Mean	239		6.22	192		4.67
Standard Deviation	22.70		0.13	14.92		0.57
Coefficient of Variation	0.09		0.02	0.08		0.12
Mass (kg)	16912			13987		
Mean mass	3382.2			2797.4		

Figure 8 is a graphical representation of the average time taken to harvest FFB using the mechanized and manual harvesting equipment. The results revealed that in manual harvesting, the average time taken to harvest a fruit bunch was 1.68 minutes as opposed to 1.39 minutes for mechanical harvesting. The implication is that the mechanical harvester is about 22% faster than the manual sickle-pole harvester. This is similar to the 1.23 and 0.8 minutes for manual and mechanical harvesting respectively obtained by Abdul *et al*.,[6], where the time taken to cut a fruit bunch for the mechanical harvester is shorter than that for the manual harvester.

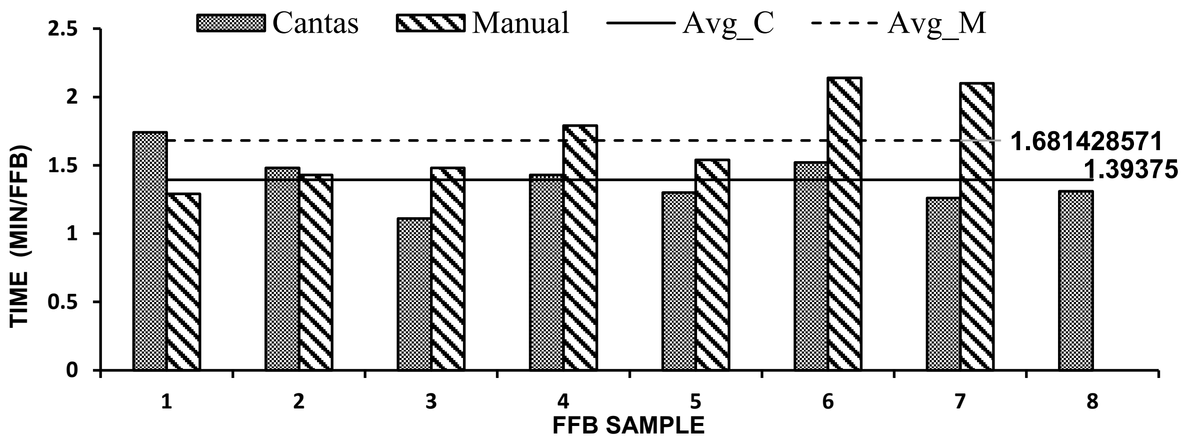

Fig. 8. Average cutting times for the manual and mechanical harvester

Figure 9 illustrates the harvesting rate for both manual and mechanical oil palm harvesting. In both harvesting approaches, the number of fruit bunches harvested increases as time increases. Furthermore, although there is a very high correlation ($0.9 \leq R \leq 1$) between the number of fruit bunches harvested and the time taken, a relatively strong correlation ($R = 0.997$) exists between the number of FFB harvested and the time it takes to harvest the said number of FFB for the mechanized harvester than that for the manual harvesting equipment ($R = 0.986$). The implication is that within a given period, the mechanical harvester produces a higher output compared to the manual harvester. This agrees with the findings of Oyedeji *et al.*, Mohamaddan *et al.*, [29, 37] in which the mechanical harvester had over 90% average harvesting capacity relative to the manual harvester.

Initially, the performance of the sickle-pole harvester in terms of quantity of FFB cut/time appeared to be better than the mechanical harvester until after 120 minutes of active harvesting when the quantity of FFB cut per time using the mechanical harvester significantly exceeded the manual harvester as indicated in Figure 9. This implies that in an agricultural landscape where mechanized agriculture is still gaining traction, a rollout of an enhance alternative to oil pam harvesting can easily be adapted to although Khor *et al.*, [30] describes the gradual adaptation as a limitation. Also, as the operators of the mechanical harvester familiarize themselves with the machine, performance rate increases as the operator's familiarity with the use of the mechanical oil palm harvester results in an increased operator proficiency required for effective harvesting of FFB [33].

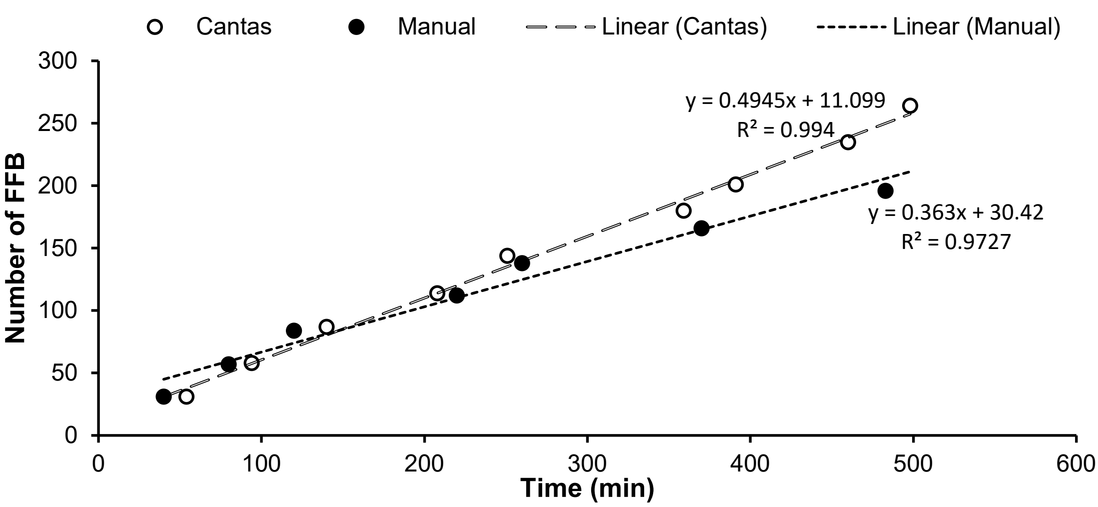

Fig. 9. A graph of the quantity of FFB harvested against time

The model developed from the analysis of the data obtained from mechanical harvesting is $y = 29.672x + 11.099$, that is Quantity of FFB = 29.67 [Time] + 11.099, which could be used to forecast the capacity of the mechanical oil palm harvester at any given time [31]. Conversely, the model developed from the analysis of the data obtained from the manual harvesting is $y = 21.782x + 30.42$, meaning Quantity of FFB = 21.78 [Time] + 30.42. This could also be used to forecast the capacity of the manual sickle-pole harvester at any given time [31]. Using the models for predictions, Table 5 indicates that working with the mechanical harvester for 8 hours, it is possible to harvest 249 FFB, while at the same time, the manual harvester is likely to harvest 205 FFB. This means that within the 8-hour duration, the mechanical harvester can harvest about 22 % more FFB than the manual harvester. This percentage improvement is less than the 43-48 % suggested by Mohamaddan *et al.*, Ruiz *et al.*, [37, 40].

Table 5
Forecast of the capacities of the mechanical and manual harvester**s**

Type of harvester	Model	t_1 (h)	C_1 (FFB)	t_2 (h)	C_2 (FFB)
Mechanical	$y = 29.672x + 11.099$	8	249	12	367
Manual	$y = 21.782x + 30.42$	8	205	12	292

* t = Time (hours) and C = Capacity (FFB)

The authenticity of these predictions is determined by the coefficient of determination (R^2) for the two harvesters, which indicates the level of certainty with which the predictions are made with the models developed for the two equipment [32]. The coefficient of determination for the mechanical harvester is $R^2 = 0.994$ and that for the manual harvester is $R^2 = 0.9727$. The implication is that predictions made by the models for the mechanical and manual harvesters are 99.4 and 97.27 % respectively accurate. Farmers in Ghana have not adopted it as the primary harvesting mechanism due to nonavailability and higher cost implications [36]. The contribution to knowledge is the predictive model developed that enhances precision agriculture.

3.4 Machine Parameters of the Mechanical Harvester

Table 6 illustrates the machine parameters of the mechanical harvester. The operating torque was obtained using Eq. (2) and Eq. (3). These parameters limit the overall output of the machine to the output permissible by the specifications in Table 5. When compared to the 561 FFB/day obtained by Azman *et al.*,[15] under similar machine parameters, the 239 FFB obtained for this study is lower due to the machine operator's inadequate operating skills. The overall implication is that these machine parameters are constant factors that will not make a significant difference if the machine operator's proficiency which is a variable is not enhanced through adequate training and exposure.

Table 6
Machine parameters of the mechanical harvester

Machine parameter	Value
Capacity	239 FFB/day
Engine speed	6222 rpm
Operating torque	0.078 Nm
Weight of harvester	9 kg
Total length	5.2 m
Range of pole adjustment	0 - 1.6 m

3.5 Hypothesis Testing

This hypothesis focuses on the statistical analysis of the capacity of the mechanical harvesting machine as a consequence of the experiment conducted. To ascertain the statistical significance of the capacity of the mechanical harvester compared to the manual harvester, the manufacturer's claim was tested using data collected from the field. Table 7 summarizes the results of the statistical analysis at significance level α = 0:05. From statistical tables, the critical t-value for a right-tailed test under this significance level is $t_c = 2.132$. The rejection region for this right-tailed test is therefore {t: t > 2.132 FFB}. From Table 7, since the calculated t = -31.619 < $t_c = 2.132$, it is concluded that the test failed to reject the null hypothesis. In addition, since the critical sample mean is greater than the sample mean ($\bar{x}_c = 581.644 > \bar{x} = 239$), the test failed to reject the null hypothesis.

From the hypothesis testing, since the test failed to reject the null hypothesis, the alternative hypothesis that "the mean daily capacity of the mechanical harvester is more than 560" is rejected and the null hypothesis which states that "the mean daily capacity of the mechanical harvester is not more than 560" is accepted. The 239 FFB/day obtained for this study is not consistent with the hypothesis developed for the study and the implication is that it is influenced by ergonomics.

Table 7
Daily capacity of the mechanical harvester

Day	Capacity (FFB/day)	Central tendency		Statistical analysis	
1	213	Sample mean	239	Sample size	5
2	239	Standard Error	10.15	Calculated t-score	-31.619
3	264	Median	239	Critical t-value	2.132
4	219	Standard Deviation	22.70	Critical sample mean	$\bar{x}_c$ = 581.644 >239
5	258	Sample Variance	515.3	Sample mean	239
				P-value	0.9963

3.6 Aspects of Ergonomic Considerations

The power generated by the two-stroke gasoline engine of the mechanical harvester is transmitted to the cutting blade through a shaft (part 6) and a slider-crank mechanism (part 8) in Figure 5. During operation, there is vibration and the continuous exposure of the operator to the vibration coupled with the weight of the mechanical harvester initiates muscle fatigue and increases the risk of lower back pain. This is one of the novel observations made in this study about the mechanical harvester. This is in line with the findings of Yusoff *et al.*,[25] in a biomechanical vibration evaluation that excessive exposure to vibration under loading conditions breeds back pain. The implication is that a modification to minimize the vibration and the weight by exploring alternative materials for the telescopic pole will suffice. However, the ergonomic risks experienced in manual harvesting of FFB are heavy lifting, handling, pushing and pulling, awkward body posture, and repetitive movements. These observations are similar to the findings of Suleimenova *et al*., and Al-Jawadiab *et al*., [14, 26]. Conversely, mechanical harvesting reduced the implications of these risk factors since the power required to produce a cutting effect was generated by the prime mover of the mechanical harvester, unlike the manual harvester where the operator exerts a physical effort. This does not differ from the evaluation of Al-Jawadiab *et al*., [26], thus making the use of mechanical harvesters ergonomically friendly in relative terms.

The inclination of the mechanical harvester, and the height of palm trees, which determines the required adjustment to the telescopic pole of the machine and their relationship is a great determinant of the level of comfort and fatigue associated with the use of the machine and characterizes ergonomics. Figure 10 presents the graph of machine inclination to the horizontal and adjusted pole length against the effective height of the palm trees, crucial ergonomic variables in the use of the mechanical harvester [35]. Further, Table 8 presents the central tendencies and measures of dispersion in the analysis of the ergonomics. From Figure 10 the machine inclination to the horizontal plane increases as the effective height of the palm trees increases. The pole adjustment range of 0-1.6 m increases as the effective tree height increases. These trends imply that harvesting palm fruits requires suitable pole length and inclination for optimum output.

Although there is a strong correlation between the Inclination and the effective tree height as well as the level of pole adjustment and the effective tree height, a relatively stronger correlation (R = 0.84) exists between the Inclination and the effective tree height than that for the level of pole adjustment and the effective tree height (R = 0.79). The predictive model developed from the analysis of the data obtained from relating the Inclination of the pole of the mechanical harvester to the effective tree height implies that: Pole Inclination = 1.805 [Tree Height] – 2.5404, can be used to forecast the Inclination of the pole of the mechanical harvester to the horizontal plane. Similarly, the model developed from the analysis of the data obtained from relating the adjusted machine pole length and the effective tree height, that is: Adjusted Pole Length = 4.95 [Tree Height] + 34.62**,** can be used to forecast the adjusted machine pole length at a given tree height.

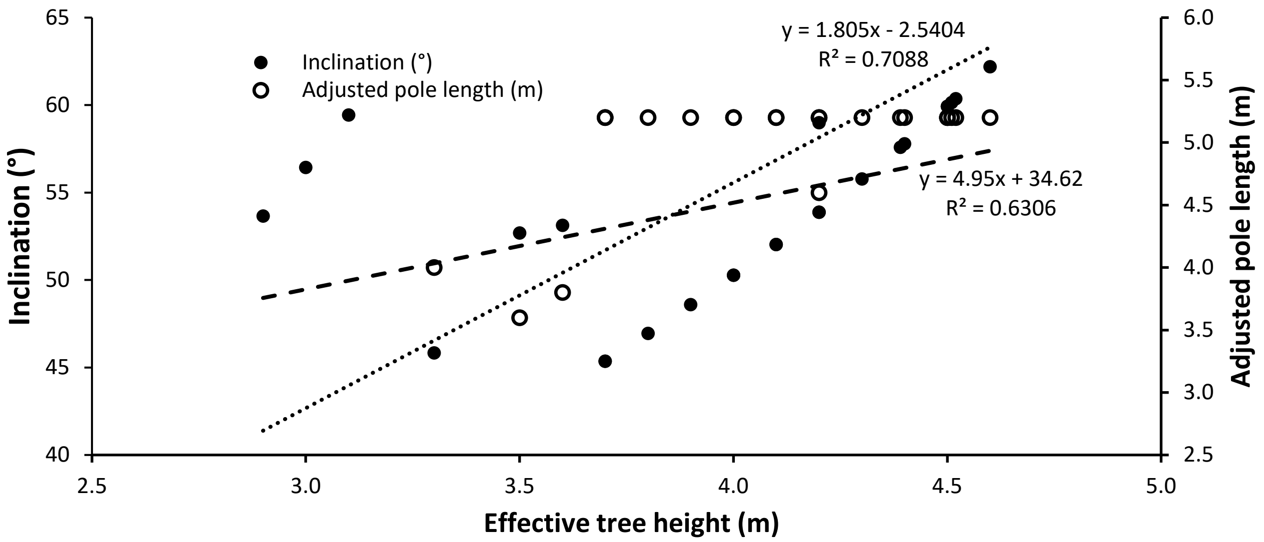

Fig. 10. Machine inclination, pole adjustment by height of palm tree

Table 8
Analysis of ergonomic considerations in mechanical harvesting

	Actual tree height [O] m	Eff. Tree height [o = O – 0.8]	Machine Length [h] m	Range of pole adjust. (m)	Inclination to the horizontal [$\theta = \sin^{-1}(o/h)$]	Operator height = 1.6 m
Min.	3.700	2.900	3.60	0.0	45.360	-
Max.	5.400	4.600	5.20	1.6	62.204	-
Mode	5.000	4.200	5.20		59.927	-
Mean	4.782	3.982	4.92		54.329	-
Std. Dev.	0.503	0.503	0.54		5.184	-
Co-eff. Var.	0.105	0.126	0.11		0.095	-

Table 9 illustrates predictions made by using these models developed from the data obtained. The authenticity of these predictions is determined by the coefficient of determination (R^2) for the two parameters (inclination and level of pole adjustment), which indicates the level of certainty with which the predictions are made with the models developed. The coefficient of determination for the inclination is $R^2 = 0.7306$ and that for the level of pole adjustment is $R^2 = 0.7288$. The coefficient of determination implies that, the predictions made for the inclination are 73.06 % accurate and that for the pole adjustment are 72.88 % accurate [35].

Table 9
Forecast of inclination and level of pole adjustment

Parameter	Model	$T_1 = 4.6\,m$	$T_2 = 5.5\,m$	$T_3 = 5.8\,m$
Inclination (°)	$y = 4.95x + 26.7$	49.47	53.93	55.41
Pole adjustment (m)	$y = -0.9025x + 5.3142$	1.16	0.35	0.08

*T = Tree height of the oil palm

4. Conclusions

Although the mechanical harvester significantly shows higher capacity and efficiency compared to manual harvester making it compelling for their adoption, and the hypothesis establishes the statistical significance and determines the mean daily capacity of the mechanical harvester to exceeds 560 FFB/day, yet the outcome of this study obtained a daily capacity of 239 FFB/day because the overall output is affected by ergonomics and operator proficiency, thus distinguishing this study and contributing to knowledge. Also, the ergonomic risks that come with manual harvesting are mitigated by mechanical harvesters. Correctly orienting one's self to attain an optimum inclination and accurately adjusting the pole length are significant for higher operator comfort, efficiency and minimal fatigue since the model developed for the relationship between these two ergonomic parameters and the effective tree height obtained a coefficient of determination of 0.6306 and 0.7088 respectively. This reiterates the importance of ergonomics in designing and using harvesting equipment.

5. Recommendation

It is highly recommended that, further research should focus on improving the ergonomics of mechanical harvesters to improve operator efficiency, comfort, and reduce fatigue. Also, training programs and interventions that address operator proficiency in correctly orienting and adjusting harvesting equipment should be explored to maximize the potential of mechanical harvesters by addressing the factors identified that influence their daily capacity and efficiency.

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