Development of a support mechanism for the use of motorized oil palm fruit bunch cutter

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Abstract: In this study a support mechanism (SP) for a palm fruit bunch harvester was designed, fabricated and tested on a plantation. This was with a view to adapting the cutter for harvesting tall oil palm trees in Nigeria. The design concept for the support mechanism was conceived as a mast pyramid which simulates an adjustable ladder pivoted on wheels comprising three segments, namely: the wheels which facilitate easy movement within the plantation; the lower segment, which comprises the stands and the upper segment which comprises the chamber (equipped with a platform) in which the operator (the climber) stands. The support mechanism was tested in comparison with the existing rope-and-knife (RK) method. The harvesting parameters used are time to climb up the palm (TU); time to cut (TC); time to come down from the palm (TD); number of bunches harvested (NB) and total time of harvest (T). A regression analysis was carried out on the data collected using Statistical Analysis Software (SAS) package. The result shows that using the support mechanism for the motorized bunch cutter was easier than rope and knife (RK). The average time of harvest T, TU, TD, and TC per tree, for the SP and RK are 190 s and 391 s; 21 s and 152 s; 21 s and 103 s; and 147 s and 134 s, respectively. The total time of harvest for RK is over 100% more than the time of harvest for SP. The time of harvest per hectare for SP and RK are approximately 9 h/ha and 20 h/ha, respectively. The comparison of SP and RK shows that there is a significant difference in TU, TD, NB, T, but there was no difference in TC, ($p < 0.05$). The study concluded that the support mechanism shows promise in enhancing the use of the motorized bunch cutter for tall palms and hence should be adopted.

Keywords: oil palm, harvesting, motorized-harvester, support-mechanism

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1 Introduction

Oil Palm (Elaeis guineensis Jacq.) originated from the equatorial tropical rain forest region of Africa, along the Gulf of Guinea. It exists in the wild type and cultivated state. The main belt runs through the southern latitudes of Cameroon, Côte d'Ivoire, Ghana, Liberia, Nigeria, Sierra Leone, Togo and into the equatorial region of Angola and the Congo. Oil palm was first illustrated by Nicholaas Jacquin in 1763, hence its name, Elaeis guineensis Jacq (Sundram, 2013). During the 14th to 17th centuries, some palm fruits were taken to the Americas and from there to the East. The plant appears to have thrived better in the East, thus providing the largest commercial production of an economic crop far removed from its origin. The oil palm is an indigenous plant across tropical countries in Africa. Historically, it emerged an important produce in the 18th century with an economic system which revolved, to a large extent, around the oil palm (Aghalino, 2000).

Processing of oil palm fruit among other parts of the oil palm yields various derivatives. The two most important products of oil palm are palm oil and palm kernel oil, both obtained from the fruit bunches. According to Gupta (2012), palm oil will account for more than 34% of Nigeria's total vegetable oil supply by 2020. Palm oil as an agricultural product is a source of edible and technical oils, thus making it a must-grow for farmers in countries with high rainfalls (minimum 1600 mm/year) in tropical climates within 10^0 of the equator

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(Geoffrey, 2006). Outside Africa, however, palm oil yields in South East Asia are falling and Crude Palm Oil (CPO) export tariff has been increased while export tax on refined products have been reduced in Indonesia to promote effective processing. Furthermore, Malaysia has increased its Crude Palm Oil (CPO) export quota by two million tons annually free of tax (APEC, 2013). In Nigeria, palm oil production output has not been encouraging with an annual output of less than a million tonnes which is less than the demand for domestic and industrial uses (Index mundi, 2014). The reasons adduced for this are less attention paid to agriculture in general, low yield from aging palm trees that are not replaced, inadequate extension services and lack of appropriate technology for palm oil production (of which harvesting is included) among others (Owolarafe, 2007)

In agriculture, harvesting is the process of gathering mature crops from the fields. Harvesting in general usage includes an immediate post-harvest handling, all of the actions taken immediately after removing the crop-cooling, sorting, cleaning, packing-up to the point of further on-farm processing, or shipping to the wholesale or consumer market. Tree crops other than oil palm (e.g. citrus, coffee, date palms, avocados, figs, Olive etc) may be hand-harvested with or without any aid. Otherwise harvesting machines are used. In hand-harvesting, the harvester (picker) climbs unto tall trees to detach ripe fruits and then throws them onto the ground for subsequent handpicking. Otherwise, while standing on the ground, he may use a long pole to knock off the fruits. The ladder is one of the harvesting aids adopted to assist the fruit picker. Some fruits harvested by the ladder method are citrus, date palms and avocados. The picker sets the ladder on the tree trunk and gets to the fruits by climbing over it. He may climb with a bag to collect the fruits (Aramide, 2015).

In oil palm production, harvesting has been presenting serious challenges to local farmers. Most shake-and-catch mechanical harvesting devices for other fruit crops cannot be adapted to oil palm (Futch et al., 2006). Harvesting involves cutting the underlying palm fronds and the stalk of the bunch, afterwards it is allowed to fall freely on the ground (Owolarafe and Arumughan, 2007), otherwise a ripe fruit naturally loosens itself from the bunch and drops on the ground. Adetan et al. (2007) reported some methods used for harvesting oil palm fruits. Locally, short trees within arm-reach are harvested using either the cutlass or the chisel to cut the bunches and frond. An ancient method for very tall trees above 9 m in height is the use of rope-and-cutlass (Figure 1). The harvester manually climbs the tree by the use of a rope tied around the tree and his torso. Once within arm-reach of the crown, the harvester uses a cutlass or axe to cut the fronds and bunches. Medium-height trees beyond arm-reach up to a height of about 9 m are harvested using the bamboo pole with a sickle is attached to one of its end. The length of the pole depends on the average height of the trees on the plantation plot to be harvested. The harvester stands on the ground while the pole and knife are raised to the tree crown in order to harvest the bunches. A major limitation of this device is the harvesters' hand-pole slippage while cutting and bending of the pole at certain heights beyond what the man handling can handle. Another method is the aluminum pole and knife in which a 40 mm diameter aluminum tube replaces the bamboo pole, however, the drudgery involved is still presenting serious limitations for local application. However, recently the Malaysian Palm Oil Board (MPOB) developed a motorized cutter for palms of middle height. Preliminary tests observed it to be quite effective on some Nigerian palms, a major limitation being that this cutter can only harvest palms up to 4.5 m (Aramide et al., 2015); whereas an oil palm tree may keep producing fruits for over 50 years by which its height would be far above 9 m. Consequently, in this work, the development of a support mechanism that would be useful in the adaptation of the motorized cutter to Nigerian palms was undertaken.

Figure 1 Harvesting using traditional method

2 Materials and methods

2.1 Preliminary investigation

In order to specify dimensions of the support mechanism, preliminary investigations were carried out to determine the height of oil palm trees, and the weight of the climbers. The heights of oil palm trees were measured using measuring tape. After 150 replications on five randomly chosen plots, the mean height was found to be 9.31 m. The mean of the heights in relation to the maximum height of the motorized harvester determine the maximum height of the support mechanism. The weights of the climbers were measured with the aid of a weighing scale. After about 11 replications from different plantations, the mean value was obtained to be 74.20 kg.

2.2 The Support mechanism

Design considerations

i. Ease of assembly and disassembly: the component parts of the proposed support mechanism must be easy to assemble while preparing for the day's job and be easy to disassemble after the day's job.

ii. Stability: the terrain of the oil palm plantation is not always flat, sometimes it could be sloppy, hilly, undulating, marshy, and peat terrain. Regardless of the topography of the plantation, the support mechanism must maintain its stability.

iii. Minimal weight and compactness: the choice of component parts should be that of light weight. The use of hollow pipes and fittings was therefore conceptualized.

iv. Simplicity: the design must be simple enough for an illiterate farmer to work with (including the assembling and disassembling).

v. Safety: the safety of the climbers must be secured while working with the support mechanism; a protective shield must be incorporated, this would protect the operator from the falling fronds and bunches, also a braking system must be incorporated, this would prevent the support mechanism from rolling off during operation in a sloppy plantation.

vi. The operator with the help of the motorized bunch cutter, while on the support mechanism, must be able to harvest bunches from oil palms up to 9 m in height.

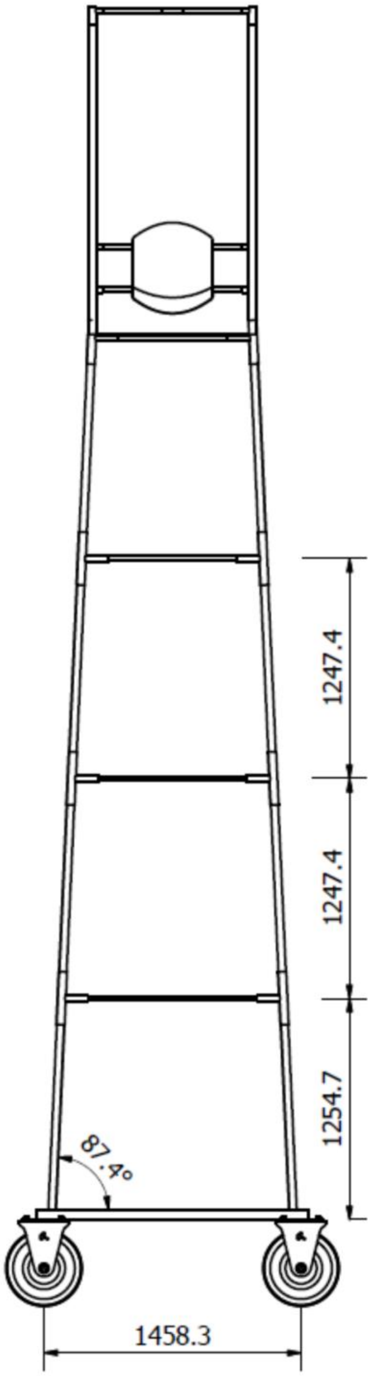
vii. The mechanism must be able to support both the weight of the operator and the bunch cutter at the same time.

viii. Since the mechanism is about 5 m high, a means of climbing was incorporated with the design.

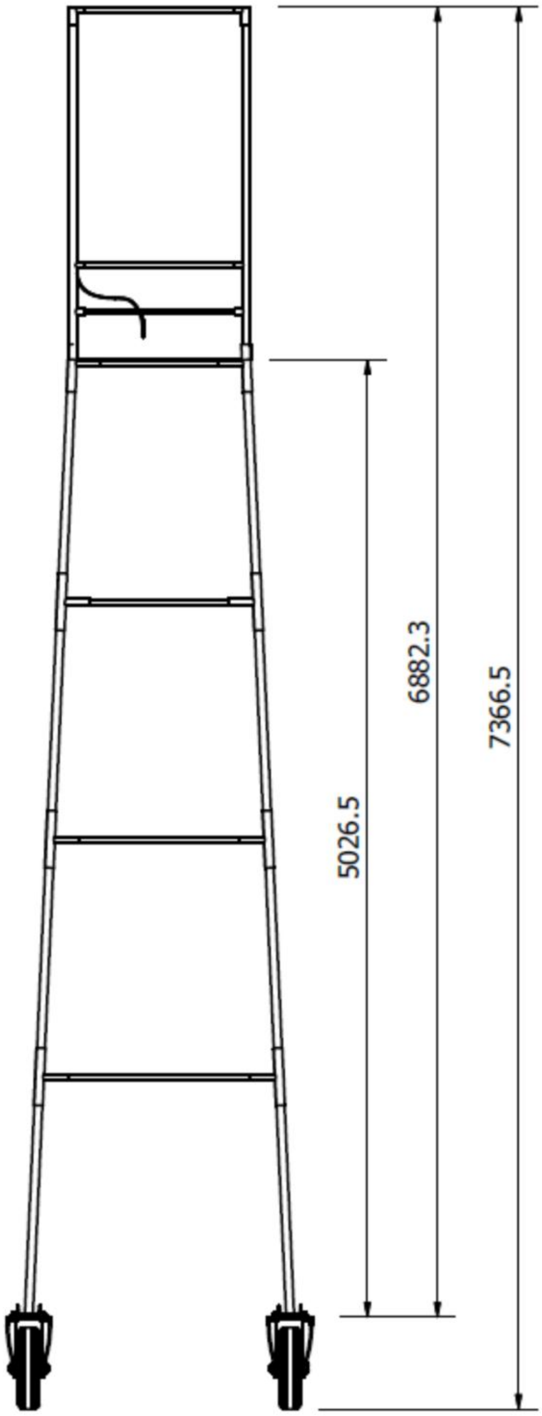
ix. Since the support mechanism would be moved from palm to palm during harvesting, wheels must be incorporated for easy movement.

The mechanism simulates an adjustable ladder pivoted on wheels comprising three segments, namely, the wheels which facilitate easy movement within the plantation; the lower segment which comprises the stands and the platform upon which the operator (climber) stands; and the upper segment which comprises the chamber in which the operator stands. Based on the foregoing, the support mechanism was taken as a 7 m mast pyramid and maximum operating height of 5 m. Figure 2 shows the orthographic drawing of the mechanism. Considering the poles as cantilevers, deflection and strength analyses were carried out (Khurmi and Gupta, 2005) on materials for construction. Table 1 shows the chosen parameters, while Figure 3 shows the shear force, bending moment and deflection diagram of the support mechanism and Figure 4 shows the Isometric view of the frame assembly with some labeled parts.

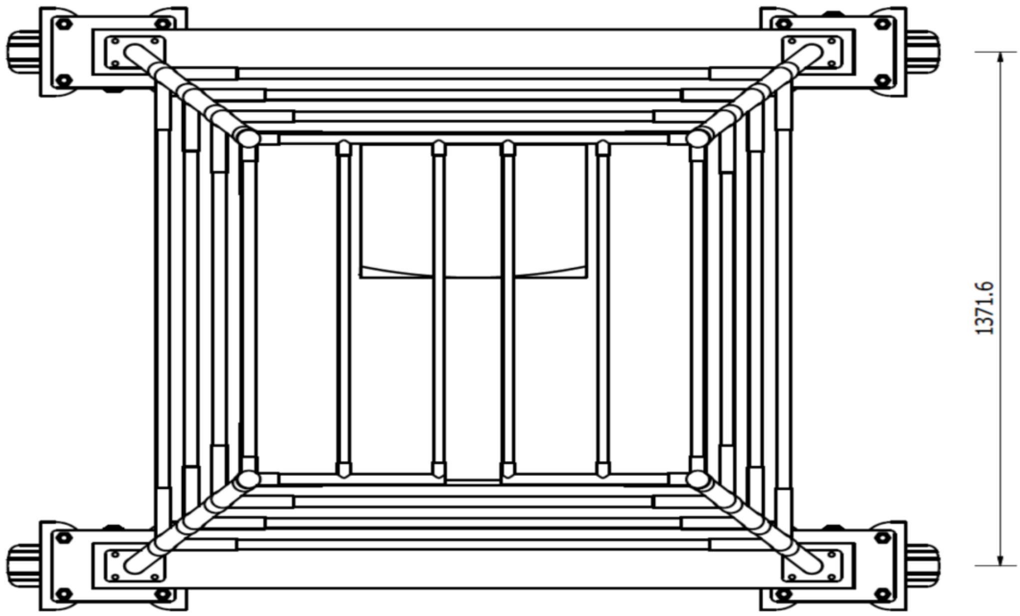
Two different types of iron poles were used to construct the component parts. A 42.4 mm diameter and 2 mm thickness pipe was used to fabricate the main stands (pillars). This was sub-segmented into four parts, each of approximately 1.3 m in vertical height, and was inclined at an angle of 87.4^{o} to the horizontal. The platform was a square of 0.9 m, and a 26.9 mm diameter and 2 mm thickness pipe was used to braze the main stand at its sub-segment. The ladder was made from 20 mm × 20 mm × 2.5 mm square pipes such that it could be folded and unfolded. This was hung on the frame of the mechanism and it was used to climb up and down the support mechanism.



a. Front view



b. Side view



c. Top view

Figure 2 Orthographic drawing of the mechanism

Table 1 Summary of the design parameters

Components	Formula	Design parameters	Used parameters
Ladder rungs	d = $(\frac{6M}{b.S_t})^{1/2}$	16.80 mm factor of Safety= 4	20 mm by 20 mm bar
Ladder deflection	$\delta_{max} = \frac{WL^3}{192EI}$	1.29×10^{-6} mm	
Ladder pole	S_p = Mc/I	26 N/ mm^2 < S_t	adequate
Main bar		18.27 mm factor of Safety= 1.8	26.9 mm
Main frame	S_p = Mc/I	70.5 N/ mm^2 < 310 N/ mm^2	Adequate
Main frame deflection	$\delta_{max} = \frac{WL^3}{48EI}$	1.83 mm	
Platform beam	S_p = Mc/I	50.07 N/mm^2 < S_t	Adequate
Platform beam deflection	δ_{max} = WL^3/3EI	0.0000568 mm	
Platform	t= $\{b^2W/4S_b\}^{1/2}$	2.05 mm factor of Safety= 1.8	2.50 mm

Note: S_t = allowable tensile strength = 160 N/mm^2

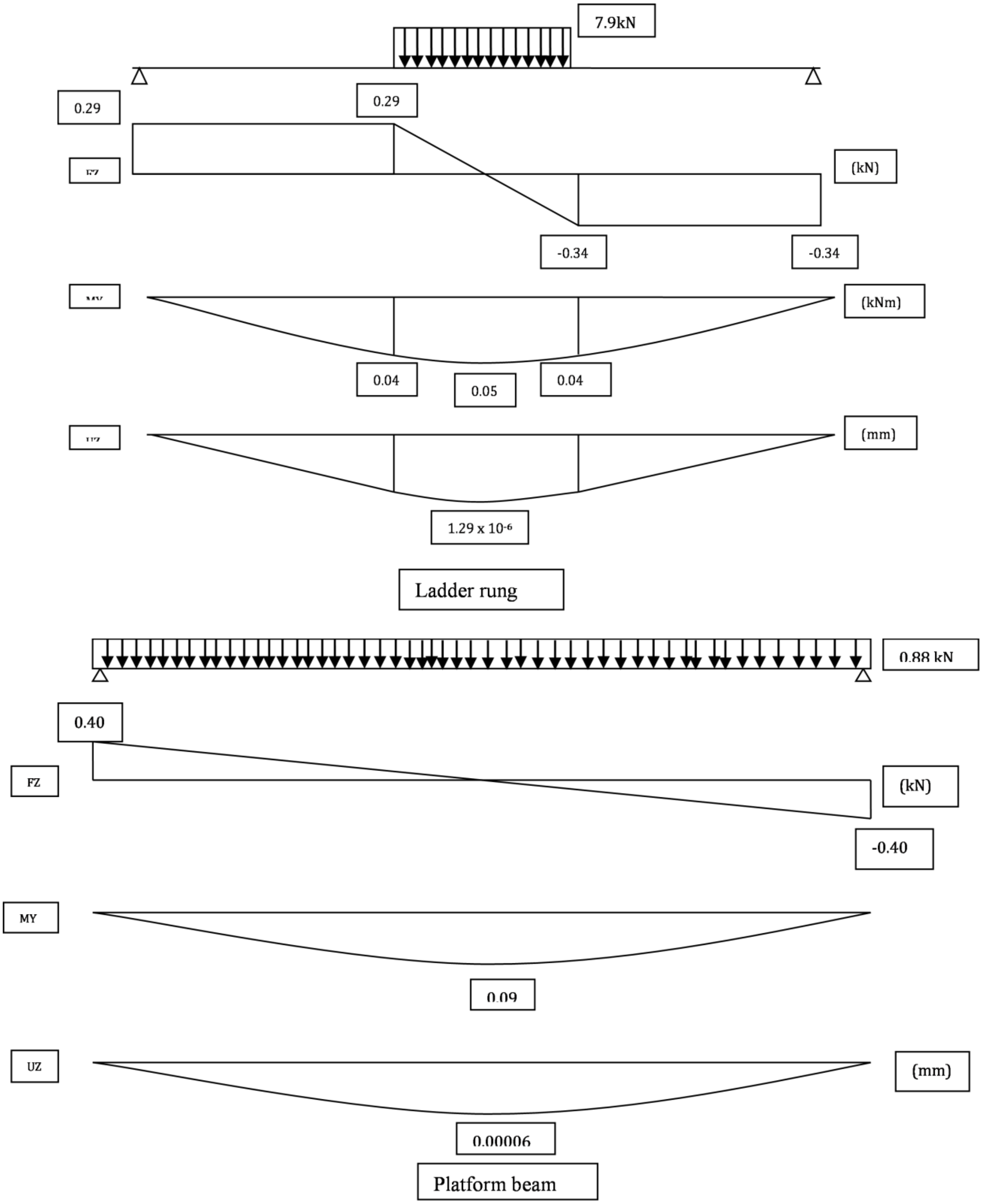


Figure 3 Shear force, bending moment, and deflection diagram of the support mechanism

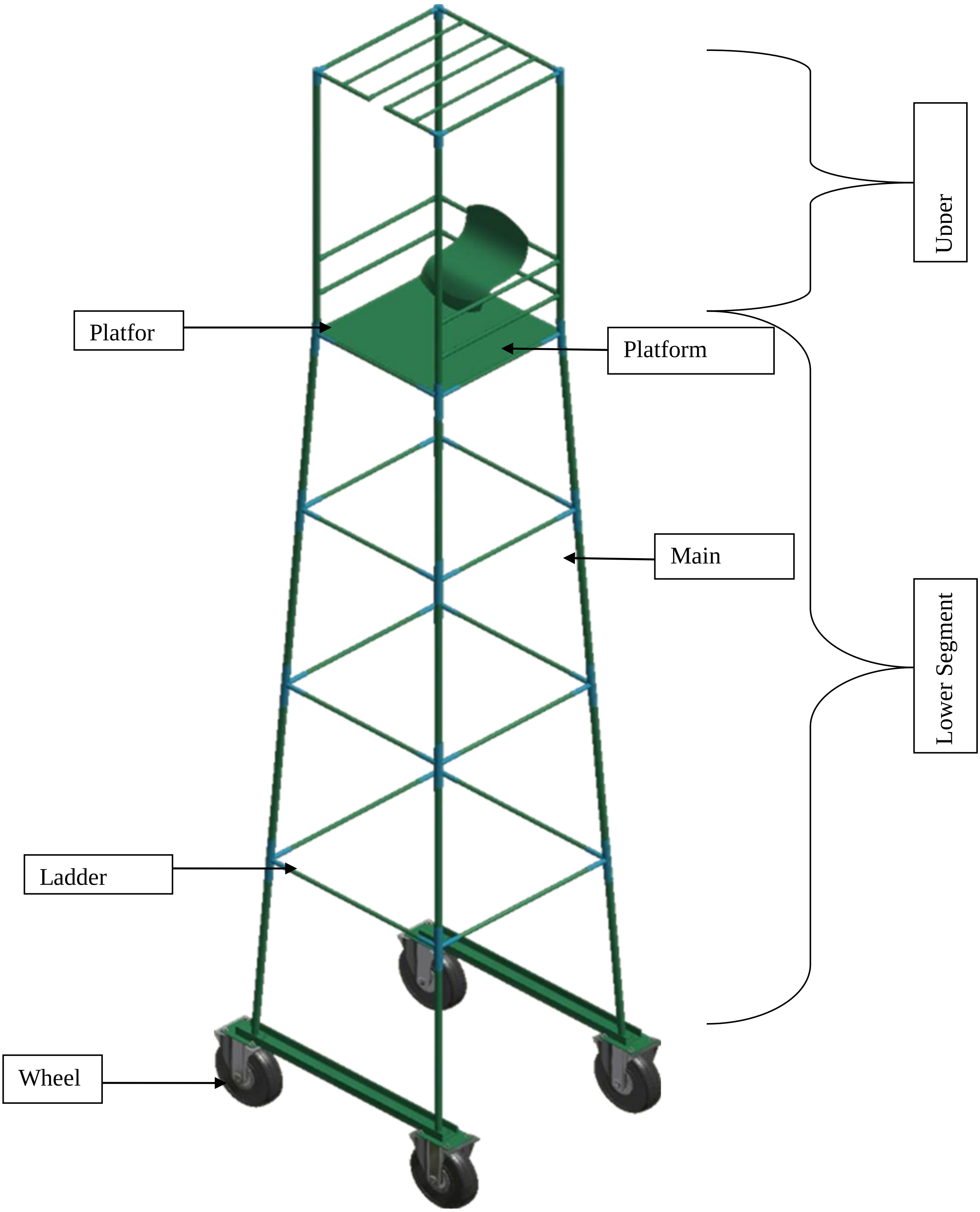


Figure 4 Isometric view of the frame assembly with some labeled parts

The assemblage of the experimental support mechanism on the farm and its use with the motorized harvester is shown in Figure 5.

2.3 Field test

By local practice, harvesting of oil palm is carried out by a crew of three, comprising one bunch and frond cutter who also stacks the cut fronds along the row, one fruit collector who searches for and picks both the fruit bunches and the scattered loose fruits and a transporter who uses a head pan to carry the fruit bunches and the loose fruits to the truck collection centres on the field, (Aramide et al., 2015). Based on previous work (Adetan and Adekoya, 1995), harvesting of oil palm was broken down into five separate activities which can be classified as: (i) locating, reaching and cutting of the ripe fruit bunches and underlying fronds; (ii) stacking of the cut fronds along the row; (iii) searching for and collecting the cut fruit bunches and the scattered loose fruits from the ground; (iv) transporting the fruit bunches and the loose fruits to the collection centres on the field, and (v) loading the fruit bunches and the loose fruits into vehicles. In this study, data were collected only on the first activity.

The support mechanism (SP) was fabricated and tested with the harvester on some plantation in comparison with existing method, namely the rope-and-knife (RK) method. The support mechanism was designed such that it could harvest oil palms at different height, ranging from 5 to 15 m. Prior to the harvesting operation, the operator first visited the farm where harvesting was to be done, and he noted the height of palms on the plot (the height of palms in a particular plot would normally be relatively the same).

Figure 5 Assembly and use of support mechanism with motorized harvester

This helped the operator to determine the number of gangs of the mechanism to be brought to the plot for assembly. The test was carried out on the State of Osun Ministry of Agriculture oil palm plantations situated in Ile-Ife, Osun State, Nigeria. The farm is a standard plantation and a representation of the farms with tall palms.

The average height of the palms on the field was 15 m. One hundred palm trees were visited; this was replicated on three different plots. The means of the three replicates were analyzed. The study determined the effect of some harvesting parameters on the harvesting methods. The time taken to climb up the palm (TU), time to cut (TC), time to come down from the palm (TD), number of bunches harvested (NB), total time of harvest (T), and relative topography of the plots were noted.

The data collected were subject to regression analysis to compare differences between harvest parameters on harvesting time between Support mechanism and Traditional (rope and knife) methods. The analysis was carried out through Statistical Analysis Software (SAS, 2002).

2.4 Challenges

There were few problems arising during fabrication, assembly and testing. In order to assure smooth functionality of the support mechanism there are some factors that were considered. For example, in fabrication, the tolerance and the parameter need to be measured correctly. Machining technique and fabrication also need to be selected properly. When this was not done properly it reduced the stability of the mechanism. During the laboratory testing phase, another problem was discovered; when the wheels were installed the mechanism was rolling off. This problem was tackled by the installation of a braking system to the wheels. During the field test the mechanism worked perfectly on a relatively flat field, but the stability reduced on the field with topography of higher degree of inclination.

3 Results and discussion

The topography of the plots visited is relatively flat. The average time taken to climb up to the crown of the palms for rope and knife is 152 s compared to 21 s (see details in Table 2) for the mechanism. This shows that climbing up the mechanism is faster than climbing up using rope and knife; climbing down is also faster with mechanism than with the traditional method (average time to climb down the mechanism and that of traditional method are 21 s and 103 s, respectively). This invariably reduced the total time taken to harvest and energy expended is reduced. According to Adetan et al. (2007), the Modified Pole and Knife can harvest palms up to 9 m of height conveniently, but the support mechanism harvest up to 15 m height of palms.

Table 2 Comparison between support mechanism and traditional method

Index	Traditional method	Support mechanism	Remark
Time to climb up, s	152±5	21±0	Mechanism is faster
Time to come down, s	103±3	21±0	Mechanism is faster
Time to cut, s	134±4	147±6	Traditional method is faster
Total time of harvest, s	391±12	190±6	Mechanism is faster

Note: Mean values and standard errors are presented.

The average number of bunches harvested by each of the methods is approximately one bunch. The average time it takes to harvest one bunch using SP is 190 s and it takes 391 s (see details in Tables 2 and 3), using RK method; this is over 100% more than the time of harvest for SP. The time of harvest per hectare for both SP and RK are approximately 9 hr/ha and 20 hr/ha, respectively. It could be observed that the support mechanism with motorized bunch harvester is faster and better than the traditional rope and knife methods. The statistical analysis (in Table 4) indicates that the effect of TC was not significant, and was found to be relatively the same for both SP and RK (see Table 3). However, the effect of TU, TD, and total time of harvest were significantly different. This was confirmed by the values gotten in Table 3

Table 3 Average of the dependent variables for the SP and RK

Dependent variables	Average of parameters	
	SP	RK
TU ,s	21±0	152±5
TC ,s	147±6	134±4
TD ,s	21±0	103±3
Total time of Harvest (s)	190±6	391±12

Note: TU --- Time to climb up; TC --- Time to cut; TD – Time to come down; SP --- Support mechanism method RK --- Rope & knife method

Table 4 The result of SAS analysis of the Comparison between Support Mechanism and Rope and knife methods

Dependent variable	Source	DF	S of Square	M of Square	F Value	Pr > F
Time to climb up	Method	1	426017.2900	426017.2900	785.60	<0.0001
	Error	98	53143.4600	542.2802		
	Corrected total	99	479160.7500			
Time to cut	Method	1	4408.9600	4408.9600	3.64	0.0594
	Error	98	118722.0800	1211.4498		
	Corrected total	99	123131.0400			
Time to climb down	Method	1	169496.8900	169496.8900	694.72	<0.0001
	Error	98	23909.8600	243.9782		
	Corrected total	99	193406.7500			
Bunches	Method	1	1.00000000	1.00000000	4.31	0.0406
	Error	98	22.76000000	0.23224490		
	Corrected total	99	23.76000000			
Total time	Method	1	1015660.840	1015660.840	224.17	<0.0001
	Error	98	444007.520	4530.689		
	Corrected total	99	1459668.360			

4 Conclusions

From the results obtained from the evaluation and testing and from various data sets collected, the following conclusions can be reached:

i. The support mechanism with motorized bunch harvester (SP) is faster, time saving and energy conserving than the traditional (RK) method.

ii. The time of harvest per hectare, of oil palms as high as 15 m, for both SP and RK are approximately 9 h/ha and 20 h/ha, respectively.

iii. The support mechanism with motorized bunch harvester harvests palms up to 15 m of height. This is an advantage over previously developed methods.

iv. The support mechanism shows promise in enhancing the use of the motorized harvester for taller palms and hence should be adopted.

As mentioned earlier, the mechanism worked perfectly on a relatively flat field, but the stability reduced on the field with topography of higher degree of inclination. Hence, it is recommended that a further study be carried out such that the mechanism would be able to work perfectly on the field with topography of higher degree of inclination.

The support mechanism can hence be used successfully on a well kept plantation, of relatively flat terrain.

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