TECHNOLOGY & PRODUCT DEVELOPMENT RESEARCH DEPARTMENT

1.0 RESEARCH THEME: DEVELOPING PRE-HARVEST TECHNOLOGIES FOR OIL PALM

2.0 PROJECT TITLE: 2022 PROGRESS REPORT ON DESIGN FABRICATION AND ANALYSIS OF OIL PALM FRUIT HARVESTING SICKLE

3.0 BRIEF BACKGROUND AND LITERATURE REVIEW

In oil palm field cultivation and propagation, most of the operations are already being mechanized. This includes land clearing, fertilizing, spraying and fresh fruit bunch (FFB) evacuation. Harvesting of FFB, however, is still done manually and this operation requires a large amount of labour.

The most common technique for harvesting tall palm trees above 9 m involved using a rope to climb the trees and a cutlass to cut down bunches and fronds, it was described as faster but not safer (Ironbar, 1981). Medium-height trees beyond arm-reach up to a height of about 9 m are harvested using a Malaysian knife mounted on a bamboo pole. A Malaysian knife, is a curved knife with the sharp edge along its convex side, the length of the pole depends on the average height of the trees to be harvested. The bamboo pole has been replaced with an aluminum pole, it works better and even faster for trees of height below 5.5 m. Above this height, bending of long harvesting aluminum poles that carry relatively heavier cutting knives on top constitutes a very serious problem. It can be shown that work efficiency declines as the day becomes hotter and approaches zero at noon, usually before 2pm.

In Nigeria, most of the tools for harvesting palm fruits are being imported, including the harvesting sickle, a jerk mechanism, and most recently a mobile engine. The harvesting sickle is connected to a jerking mechanism which produces a to and fro motion (like a hand saw) thereby enhancing harvesting efficiency. This mechanism together with the harvesting sickle blade can be powered by a small engine.

Many attempts have been made to mechanize of the harvesting of oil palms. The rope and belt method of climbing the oil palm trees to harvest bunches was described as inefficient and uncomfortable (Webb 1976), while (Adetan and Adekoya, 1995) described it as risky including fatal falls. Tractor mounted booms for carrying harvesters to the crown of the tree to harvest bunches was experimented in Honduras and Costa Rica but yet to be evaluated (Hartley 1977).

(Pierce and Cavalieri, 2002) opined that improving labour productivity, health and safety represents a major opportunity for reducing production costs. In the report by (Adetan et.al, 1997) promoted the pole and knife method as more efficient in comparison with the rope and cutlass method. (Aramide et.al., 2015) compared the pole and knife method of harvesting with the motorized bunch cutter developed by the Malaysian Palm Oil Board (MPOB) and found the motorized bunch cutter more efficient for Nigerian Oil Palm Plantations with palms between 2.5 – 4.5 meters' height. There are no reports yet for taller palms. (Makky M and Cherie D, 2021), (Onoh P A, et.al. 2021), (Akbar A R M, 2024) and (Obokare H A, 2024) described the optimum time of harvest to improve productivity of Oil Palm plantations. A new motorized cutter was presented by (Uzoma S M, 2024) with a circular cutting blade. Evaluation and comparative analysis with the motorized Malaysian cutter are not currently available. (Razali M H H, 2024) introduced remote sensing technologies to harvesting of Oil palm fruits, and (Abanga A F, 2024) showed that the pole and Knife harvesting technique still accounts for 67% of harvesting practices in Ghana.

The harvesting sickle produced by local black-smith in Nigeria are inconsistent and vary in quality. Therefore, a research to harmonise the technologies for fabricating harvesting knives was initiated, aimed at increase productivity and improving the quality of the final product, with the key objective of reducing production cost, reduce labour requirement and production time.

4.0 KEY ACHIEVEMENTS AND RESEARCH OUTCOMES

Domesticating the technologies for the production of the oil palm harvesting knives required a market survey of the available technologies in the Nigerian manufacturing industry and identifying the cheapest and best practice to ensure a competitive product. The manufacture of the harvesting knives would involve four processes as elaborated below:

1) *Fabrication process*: There are two basic technologies for this manufacturing process and both are available and cheap, including
    a. Annealing spring metals and
    b. Cutting the knives from flat metal plates.
2) *Hardness treatment*: Various heat treatment methods are available ranging from carbonizing, tempering, etc.
3) *Engraving Technologies*: Various engraving technologies are also available ranging from the manual imprinting methods (which is the cheapest option with very low quality), milling technologies and laser engraving

Fabrication Process

Various samples of the harvesting knives were fabricated from each of the aforementioned methods to be compared with the foreign product. A metal spring steel bar measuring (500 x 90 x 17) mm was purchased for this work, the spring steel bar was cut into strips with acetylene gas and annealed into the harvesting knives, then hardened. Three different experienced metal formers (black smiths) were used, this created an opportunity to study and evaluate the different quality finished products from the various workmen.

Whereas in the jig-cutting process, a low-carbon (mild) steel plate measuring (600 x 600 x 3) mm was also purchased for this work, the metal plate was simply cut into the desired shape of harvesting knives and hardened accordingly.

Heat Treatment

It would be keen to note that low-carbon (mild) steel need to be carburization and quenched, while spring steel consist of high-carbon. Therefore, based on this observation, three samples of the harvesting sickle were produced using three different combinations of the aforementioned manufacturing processes. Two knives were annealed from spring steel bars, one of which was carburized and tempered while the other was only tempered, and a third sample of the knife was cut from low-carbon steel sheet and carburized.

Engraving

The manual engraving, milling engraving and laser engraving technique were implemented, accordingly.

Structural and Material Analysis

The tensile strength of a material is the measurement of the force required to stretch a material until it breaks, while the hardness of a material describes its ability to withstand abrasive/wear loads. It is important in the design and fabrication of harvesting knives to study the tensile and wear properties of the selected materials to define their structural integrity and durability, breaking of the knives during operation may pose a serious hazard to the worker while its ability to resist wear means less service and longer service life.

Results

During the course of this work, three different samples were achieved with various combination of fabrication technique and heat treatment. The samples were labelled as numbered below.

1. SAMPLE A: Annealed spring steel knives that was tempered and engraved "NIFOR KNIVES" by manual engraving technique.
2. SAMPLE B: Annealed spring steel knives that was carburized, tempered and, then engraved "NIFOR" using the milling engraving method.
3. SAMPLE C: Mild (low-carbon) steel knives that was carburized, tempered and engraved "NIFOR" with a laser machine.

All three samples were tested and compared for tensile strength and surface hardness using the universal testing machine at the National Center for Agricultural Mechanization (NCAM) in Ilorin, Kwara state.

Table 1.0: Tensile analysis results

Parameters	**Sample**		
	NK	**NI**	**NR**
Yield force (N)	40270	44965	18370
Elongation (mm)	8.23	7.51	6.19
Yield Stress (N/mm2)	822.726	1202.614	314.017 649.858
Yield Strain (%)	20.58	18.78	6.237 15.17
Ultimate force (N)	41720	44965	22810
Elongation (mm)	9.851	7.514	8.029
Ultimate Stress (N/mm2)	854.394	1202.614	389.915
Ultimate Strain (%)	24.632	18.783	20.069

The table 1.0 shows the forces and stresses acting on each sample at yield, ultimate and breaking points, and also show the elongation of the material associated at the various points. It can be seen that the sample IN has the highest tensile properties with a Tensile stress of 1,202.614 N/mm, at a force of 44,965N, and an elongation of 7.514mm followed by the sample NK with a Tensile stress of 854.394 N/mm, at a force of 41,719.999N, and an elongation of 9.851mm while the sample NR had a Tensile stress of 389.915 N/mm, at a force of 22,810N, and an elongation of 8.029mm.

Table 2.0: Hardness test results

Parameters	Sample			
	NR	**NI**	**SBL**	**NK**
Brinell Hardness (Kg/m2)	103.1623	559.0851	336.9992	276.1546
Brinell Hardness Number	103.16	602.88	321.35	302.77
Rockwell Hardness number	61	0	108	107

The hardness test is usually directly proportional to the tensile test as proven by the results in Table 2.0. It can be observed that once again the sample IN has the highest hardness of 559085.1 Kg/m2, followed by the sample NK with a hardness of 276154.6 Kg/m2, while the sample NR has a hardness value of 103162.3 Kg/m2.

It can be observed that the sample NR had the least desirable tensile properties, this is because the knife was cut from a 3mm thick plate, while the other knives wee annealed to about 5mm thickness. From mathematical theory, the tensile stress of a material can be expressed as in equations 1 and 2, where P_{max} is the ultimate force or force exerted at the ultimate tensile stress, A_0 is the cross sectional area, w_0 is the width of sample and t_0 is the thickness of the sample.

Ultimate Tensile Strength is given by;

$$\sigma_{max} = \frac{P_{max}}{A_0} \qquad \text{(i)}$$

and;

$$A_0 = w_0 \times t_0 \qquad \text{(ii)}$$

From equation 1, it can be shown that the force exerted on the sample to achieve the ultimate tensile stress is directly proportional to the thickness of the sample, therefore if the thickness of the sample increases, the ultimate tensile stress also increases. Therefore, based on this relation, the ultimate tensile stress for a thicker sample of the same material with the same heat treatment can be estimated so that a 5mm sample of NR would have a Tensile stress of 649,858N/mm and a force of 38,016N likewise, a 6mm sample of NR would have a Tensile stress of 779,830N/mm and a force of 45,620N which is very reasonable and comparable to the other samples

It would also be keen to observe that the sample IN peaked at the yield stress, this is a characteristic of very hard materials, although they can withstand very high forces, they are brittle at their yield point failing without warning. While the samples NK and NR yielded at 822.726 N/mm and 314.017 N/mm respectively, at a forces of 40270N and 18370N, with linear elongations of 8.234mm and 2.495mm. These have the particular advantage showing signs of failure before fracture, this means in the field of operation where advance devices may not be available for checking failure, simple visuals inspections would reveal the integrity of the device and the large difference in elongation/deformity between the yield and ultimate stresses allows reasonable grace for a supervisor to observe and identify failing devices.

Discussion of Results

1. The results obtained from the sample NI is extravagant, showing an overdesign, the material is unnecessarily too hard for the function it is required to perform.
2. The samples NI and NK were fabricated from used or condemned vehicle spring metal which may not be always available at the same price. This may render the production process unsustainable.
3. It was very difficult to produce the exact shapes of the knives using the annealing manufacturing methods, the resulting knives from this method were inconsistent and poorly finished. The use an automated hammer would probably improve the quality of the knives.
4. The samples from the mild-steel plate were more consistent, requiring less manufacturing time, labor and effort with very good (presentable) surface finish.
5. The engraving with the manual imprinting method produced poor results that can be easily be imitated in the downstream sector.
6. Engraving with the milling techniques produced better and more professional (consistent) results.
7. Engraving with the laser technologies produced even better results that would be very difficult to imitate.

The results presented has exhibited that the sample (NI) produces the best physical properties for harvesting knives, but at a higher cost and with a lower through put (i.e. lower production rate), while the sample (NR) at 5mm and 6mm thickness would produce the knives with reasonable physical properties at a lower cost and higher production output. While the sample NK produced the best overall product i.e. cheaper cost of production and good physical properties, but a poor surface finish and also a low production output. This is summarized in Table 3.0.

Table 3.0: Summary of Results

S/N	SAMPLES	PRODUCTION TIME (mins)		PRODUCTION COST (Naira/USD)	PHYSICAL PROPERTIES		SURFACE FINISH
		CUTTING	HEAT TREATMENT		TENSILE STRENGTH (N/mm2)	HARDNESS (Kg/m2)	
1	Malaysian SBL	NA	NA	NGN 13,000/ USU 30.73	1143.58	336,999.2	Good
2	Annealed & Hardened (NI)	40 – 60	20	NGN 9,000/ USD 21.28	1202.614	559,085.1	Poor
3	Annealed (NK)	40 – 60	NIL	NGN 5,000/ USD 11.82	854.394	276,154.6	Poor
4	Hardened M/S (NR)	2 – 6	20	NGN 8,000/ USD 18.91	389.915	103,162.3	Good

* In 2022 the average exchange rate was NGN 423 to USD 1

The duration required for one skilled worker to anneal one knife was about 60 minutes, it is anticipated that using an automatic hammer may reduce the annealing time by about 30%. Whereas it took only about 6 minutes to cut out one knife from mild steel plate using a cutting disc, the use of a specialized jig or laser technologies for cutting the knives should reduce the cutting time by about 70% or more. The annealed knife (NK) may not incur any further cost for hardening, whereas the mild steel knife (NR) requires extensive hardening. The cost of producing the hardened annealed knife (NK) was only NGN5000, the carburized and hardened annealed knife (NI) was NGN9000, while the carburized mild steel knife (NR) was NGN8000. Whereas the cost of the foreign knife was NGN13000.

Increasing the production quantity should reduce production cost, especially in the mild steel knives (NR), where a lot of knives can be heat treated concurrently thereby reducing production time and production cost.

5.0 FUTURE RESEARCH DIRECTIONS AND THRUST AREAS

It is clear that the sample NK is the cheapest manufacturing process, but the raw material required for the fabrication is not sustainable. While the manufacturing process in NR is the most suitable and reliable process at a slightly higher cost.

The future thrust of this work would be to

1. Collaborate Agricultural Economists to investigate the sustainability of using used/condemned vehicle spring steel for fabricating the harvesting knives.
2. Investigate better and cheaper heat treatment processes for harvesting knives cut from mild steel,
3. Investigating the possibilities and potential cost of producing the harvesting knives from medium carbon steel
4. Finding production outfits with the capacity to collaborate in this research and capable of fabricating the anticipated final product.

6.0 CHALLENGES AND OPPORTUNITIES IN THE FIELD

Research is expensive (especially engineering research), paucity of fund generally leads to poor research output and low income. The participation of the private sector into demand driven research and product development would help to reduce this problem and improve research outcome.

It was shown in this work that 76% of Oil Palm plantations in Ghana utilize the harvesting sickle. It is expected that the figure in Nigeria and probably in West Africa would replicate this value. The mechanized cutter only accounts for about 3% of plantations while the rope and belt (local) harvesting method accounts for the rest. Localizing the technology for producing the harvesting knives would reduce the price thereby encouraging plantations still practicing the local harvesting method to invest in this technology and generally create income.

7.0 REFERENCES

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8.0 RESEARCH TEAM

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