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DEVELOPMENT AND PERFORMANCE EVALUATION OF A SMALL SCALE KENAF FIBRE SPINNING AND REELING MACHINE

Atta Adekunle[a], Owolarafe Oseni[b*]

[a] Kenaf and Jute Improvement Programme, Institute of Agricultural Research and Training, Obafemi Awolowo University, Moor Plantation, Ibadan, Oyo State. Nigeria, email: adekunleatta@gmail.com, ORCID 0009-0004-4079-5255

[b] Department of Agricultural and Environmental Engineering, Faculty of Technology, Obafemi Awolowo University, Osun State, Nigeria, e-mail: owolarafe@yahoo.com, ORCID 0002-6748-8704

** Corresponding author: e-mail: adekunleatta@gmail.com*

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ABSTRACT

A developed small scale kenaf spinning and reeling machine was evaluated in this study. The machine uses the principle of the ring spinning technique to produce spun kenaf-yarn (single or double-ply). The machine component includes two 0.5 kW electric motors positioned on a 640×433×10 mm mild steel frame (with speeds of the electric motors controlled by 0.5 kW variable frequency drives), twisting spindle, inlet frustum, feed roller shaft, reeling and spinning shafts, bearings, and a bevel gear. The machine was evaluated using different spinning speeds (90, 100 and 110 rpm), reeling speeds (60, 70 and 80 rpm) and a kenaf sample (Ifeken DI 400). At the spinning and reeling speeds combination of 90 and 80 rev·min^{-1}, the developed machine was able to produce a continuous length of kenaf yarn twisted at 95.5 turns per minute with a production speed of 0.94 m·min^{-1} at the highest efficiency (88.9%) of the machine. The level of twist of the spun yarn spun provides information on the required twist level for kenaf fibre as deviation from this value was discovered to cause deformation on the spun yarn. This machine was able to reduce the drudgery involved in the production of spun kenaf-yarn and the technology is expected to positively influence kenaf's growth and utilization in Nigeria.

Introduction

The increasing potential of kenaf as a significant fibre crop, has made scientists develop strong appetite for recurrent studies and research on the crop (Falana et al., 2019; Falasca et al., 2014). Apart from the origin of kenaf traced to Africa, it was reported by Cheng et al. (2004) that kenaf and other related crops are commercially grown in eastern Africa. Similarly, Olasoji et al. (2014) reported the significant impact of kenaf production in Nigeria and the development of different varieties of its seeds which are found to be disease resistant and more suitable to the ecological conditions of the country to improve its yield. Meanwhile, despite tracking the origin of kenaf to Africa, its production in this same region has still been significantly low since 1990 (FAO, 2008). However, the demand for kenaf material is still growing despite its decrease in Africa due to its increasing potentials for utilization across various industries.

Originally, kenaf was usually cultivated as a cordage crop and spun into yarn for production of different diameters of rope, twine, bags, and sackcloth (Webber and Bledsoe, 2002) but the discovery of its potential for pulping and papermaking made the crop more significant over the years (Ayadi et al., 2016). These factors have spurred the necessity for increased kenaf production, especially its suitability as an excellent alternative to synthetic materials for the packaging of agricultural produce aimed at the international market. It is also interesting to note that in Nigeria, very few farmers get involved in the production of kenaf despite government's supports (in providing viable seeds to farmers) through its agencies due to the under-utilization of kenaf that leads to low sales prospects for farmers. Nonetheless, the few interested farmers majorly depend on the Institute of Agricultural Research and Training, Moor Plantation, Ibadan, Oyo State to get different varieties of viable seeds of kenaf to produce fibres with better mechanical properties for good spinnability than some foreign varieties (Atta et al., 2021). Currently, majority of small and medium scale processors are still spinning fibres to form yarn manually across Nigeria in order to obtain valuable raw material for industrial application, as there are no available technologies or machinery for this purpose to encourage and support these processors (Oloruntoba and Jolaoso, 2017; Ogunwusi, 2003).

It was discovered that from the various spinning systems, ring-spinning system is the most popular and widely used spinning technique and is considered more suitable for wide range of fibres with its technology applicable to small scale spinning machines (Carl, 2003: Chalachew, 2014). Specifically, the ring-spinning system uses roller drafting to feed fibre into the spinning system, where it is received by a spinning spindle that performs the twisting of fibres. The twisted yarn moves to the bobbin through the traveller guide which ensures alignment of the fibre when traveling to the bobbin.

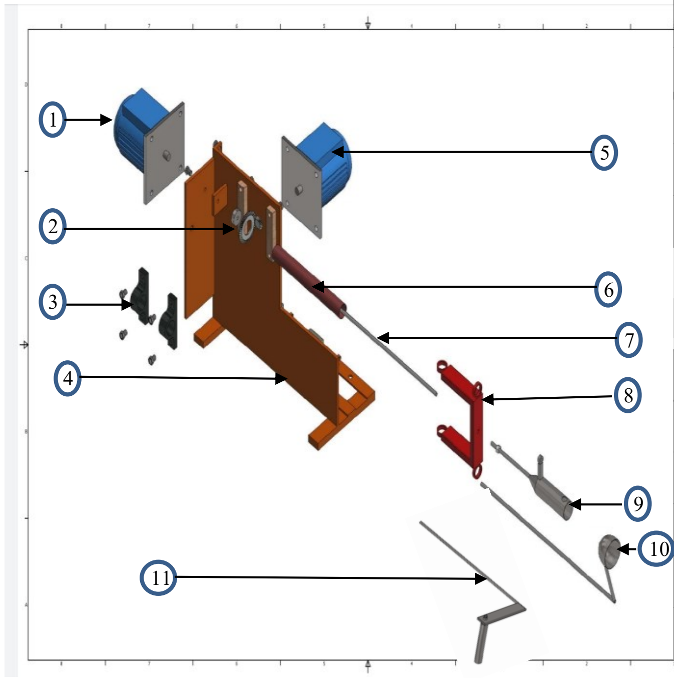
Purpose and scope of work

A small scale kenaf spinning and reeling machine using ring spinning technique has been designed but still to be evaluated. This study undertook the performance evaluation of the machine with a view to ascertain the best working condition for its optimal performance.

Materials and Methods

Description of the machine

The main components fabricated include the frame-stand which houses every other component as shown in Figure 1. The frame is a shielded metal arc welded mild steel structure with dimensions 640x433x10 mm and an attached base for the placement of the variable frequency drives (VFD). Gears used were machined to specifications using lathe machine with threads on the spinning shaft with pitches. All fabricated parts and other components were assembled to form the spinning/twining and reeling system. Figure 2 shows the design of the machine for the production of a continuous single ply yarn (twinning machine) while Plate 1 shows the set-up of the machine after fabrication for the production of a single spun yarn.



Component Description	
1	0.5 kW Spinning Motor
2	Bearing Housing
3	Plummer Bearing
4	Machine Frame
5	0.5 kW Reeling Motor
6	Reeling Shaft
7	Spinning Shaft
8	Traveller Guide
9	Spinning Spindle
10	Inlet Frustrum
11	Drafting Shaft

Figure 1. Exploded View of the Kenaf Spinning and Reeling Machine

Also, Figure 3 shows the design of the machine set-up for production of two plies spun yarn while Plate 2 shows the fabricated machine forproduction of double plies yarn. The machine was designed to produce either a single or double-ply yarn by only changing a component of the machine depending on the required output. During the process of twinning kenaf fibre, the inlet frustum is attached to the frame of the system and this process allows or enables the joining of additional lengths of the fibre. Also, reeling the twined length of kenaf fibres occurs on a bobbin attached to the reeling shaft being controlled by a separate electric motor that is interrupted for doffing when the bobbins are full of twisted fibre or spun yarn.

The shaft is designed to accommodate two bobbins to reduce doffing time and makes it easier to creel the two bobbins on the inlet shaft for twisting or production of two-ply yarn. The variable frequency drives control the speeds of each electric motor attached to the spinning and reeling shafts to some predetermined values, which were aimed at a matchable spinning and reeling speeds combination for quality production.

The following describes the different components of the machine as shown in Figure 1.

The frame

The frame is a shielded metal arc welded mild steel structure with dimensions 640x433x10 mm and an attached base for the placement of the variable frequency drives (VFD). The frame is constructed to ensure some other components can be attached easily before usage and detached conveniently after use.

Spinning and reeling electric motors

Two electric motors were used to transmit power to either the spinning shaft or reeling gears for onward transmission to the reeling shaft. For this machine, 0.5 kW electric motors were found suitable for spinning and reeling kenaf fibres into bundle with a width not greater than 5 mm.

Variable frequency drives

One 0.5kW Variable Frequency Drive (VFD) was connected to each of the electric motors to control the speed of the electric motors from minimum to the maximum speed limit. These drives enable the motors to run at varying speeds and help to determine the most appropriate speed combinations for spinning and reeling.

Spinning spindle

The spinning spindle is a major part of the spinning system that enables the joining of fibres and produces spun yarn. The spindle had a tapered design with a larger diameter of 35 mm and tapered screwed end of 10 mm to fit into the spinning shaft. Two spinning holes were also bored on the spindle with 10 mm diameter where fibres are spun and move out of the spinning section.

Traveller guide

The first hook or ring on the traveller guide receives the twisted fibre or spun yarn from the spinning section as the yarn travels through any of the spinning holes. This guide was designed to align yarn and delivers the yarn to any bobbin placed on the reeling shaft. The guide was also designed to ensure it is screwed onto the spinning shaft.

Spinning and reeling shaft

The diameters for the spinning and reeling shafts were calculated to be 10 mm and 30 mm, respectively. The length of the fabricated spinning shaft was 560 mm while that of the reeling shaft was 400 mm. The spinning shaft was supported by a deep groove ball bearing while the reeling shafts were duly supported by a plummer block bearings with corresponding shafts sizes as carefully selected in the design.

Inlet frustum

The frustum allows the passage of the fibre through its outlet of 10 mm diameter which aids the joining of fibres by twisting. The inlet frustum is a non-rotating component with a shaft that makes it detachable from the frame. Once fibres are joined and twisted on two reels, the frustum can be easily detached from the frame for the next operation.

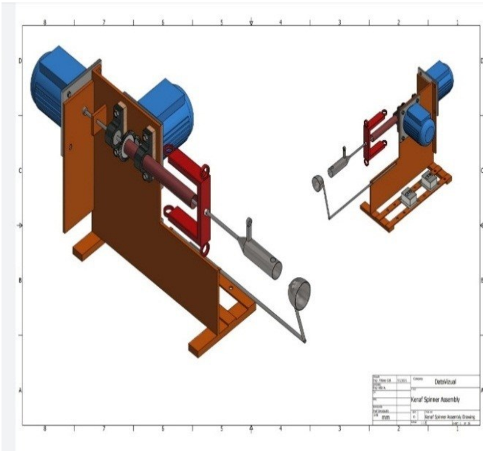


Figure 2. Design of a kenaf twinning machine

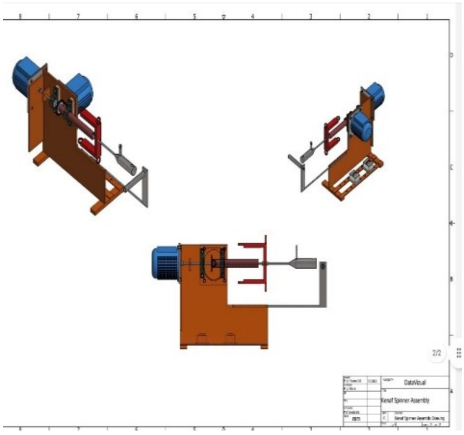


Figure 3. Design of Machine Set up as kenaf spinning machine

Foto 1. Machine Set up as a Kenaf Twinning Machine

Foto 2. Machine Set up as a Spinning Machine

Feed rollers shaft

This shaft allows the mounting of the two reels of twined or twisted fibres on it. It allows the release of the twined fibres as the reeling shaft pulls the fibre through the spinning spindle to a newly installed reel on the reeling shaft.

Reeling gears

The spinning gears transmit and change the direction of the rotary motion from the electric motor towards the spinning system. One of the gears is mounted on the spinning electric motor shaft, the other gear is on the spinning cylinder which enables the required rotation for twining, joining, and spinning to occur, with the aid of a 30 mm inner diameter plummer block bearing.

Performance evaluation of the machine

The machine was evaluated by determining the following performance parameters of the machine.

– **Determination of the spinning speed (N_1) and reeling Speed (N_2):** These are the speeds of the spinning shaft and reeling shafts driven by different electric motors. The speed of the individual shaft is measured with use of a tachometer.
– Determination of production speed or yarn delivery speed (N_3): The yarn delivery speed was determined as

$$N_3 = \pi \, d_r \, (N_2 - N_1) \tag{1}$$

where:
N_3 – yarn delivery speed,
d_r – diameter of the reeling pulley, (cm)
N_2 – speed of the reeling pulley, (rev·min^{-1})
N_1 – speed of the twisting/spinning cone, (rev·min^{-1})

Production or yarn delivery speed is measured in centimetre per minute.

– **Determination of level of twist (t):** The level of twist is very important and determines the quality of spun yarn. The level or number of turns required to produce the yarn is given as; The level of twist can be determined using the following Equation;

$$t = \frac{N_1}{N_3} \tag{2}$$

where:
t – the level of twist,
N_1– the spinning spindle,
N_3– production speed,

Determination of spinning and reeling efficiency (γ)of the machine: It was determined using the following Equation;

$$\gamma = \frac{N_2}{N_1} \times 100 \tag{3}$$

where:
N_1 is the rotational speed of the spindle and N_2 is the rotational speed of the reeling shaft.

Experimental design

The experimental design was a 1 x 3 x 3 factorial design with the samples of produced yarn collected in triplicates (as in Figure 4). The three factors considered were the spinning electric motor speed, reeling electric motor speed, and a single kenaf variety. The spinning electric motor speed was tested at 90, 100 and 110 rpm combined with the reeling electric motor speed tested at 60,70 and 80 rpm based on the preliminary test result, while the kenaf variety used was Ifeken DI 400.

Result and Discussion

Effect of spinning and reeling speed on machine production rate

The production rate of the machine ranges from 0.94 to 4.71 $m \cdot min^{-1}$ as shown in Table 1 at different spinning and reeling speeds combination. Analysis of Variance (Table 2) conducted on the collected data set revealed that the effects of spinning as well as reeling speeds were significant ($p \leq 0.05$) in determination of machine production rate. Ideally, ring spinning machines has relatively low production speed which makes the production per minute to be relatively low compared to other spinning methods (Hosne, 2011), but this principle was adopted due to its ability to spin natural fibres, unlike other systems. The production rate of a ring spinning system for large scale production is usually less than 50 $m \cdot min^{-1}$ (Carl, 2003) which makes the rate for small scale farmers and processors better compared to that of a large-scale processor and or manual processor. However, this machine was able to produce spun yarn at the various speed combinations twisted at different revolutions per minute.

Effect of spinning and reeling speed on machine efficiency

The efficiency of the machine is based on the quality of the spun yarn as shown on Table 1-3 which revealed that at different speeds combination, the efficiency of the machine ranges from 54.5% to 88.9% with the lowest efficiency having the highest production rate of 4.71 $m \cdot min^{-1}$.

Table 1.
Result of the performance evaluation of the machine

Spinning Speed ($rev \cdot min^{-1}$)	Reeling Speed ($rev \cdot min^{-1}$)	Production rate ($m \cdot min^{-1}$)	Twist evel (tpm)	Machine Efficiency (%)
90	60	2.83	31.8	66.7
	70	1.89	47.7	77.8
	80	0.94	95.5	88.9
100	60	3.78	26.5	60.0
	70	2.83	35.4	70.0
	80	1.89	53.0	80.0
110	60	4.71	23.3	54.5
	70	3.77	29.2	63.6
	80	2.83	38.9	72.7

The machine spun yarn at the rate of 0.94 m·min^{-1} at its highest efficiency of 88.9% when the spinning and reeling speeds were 90 and 80 rev·min^{-1}, respectively which also implies that best or quality yarn is produced at the lowest production speed giving an inverse relationship between production rate and yarn quality. A comparison of the machine mean efficiencies at different reeling and spinning speeds using Duncan multiple range test (DMRT) as shown in Table 3 reveals that the means are all significantly ($p \leq 0.05$) different.

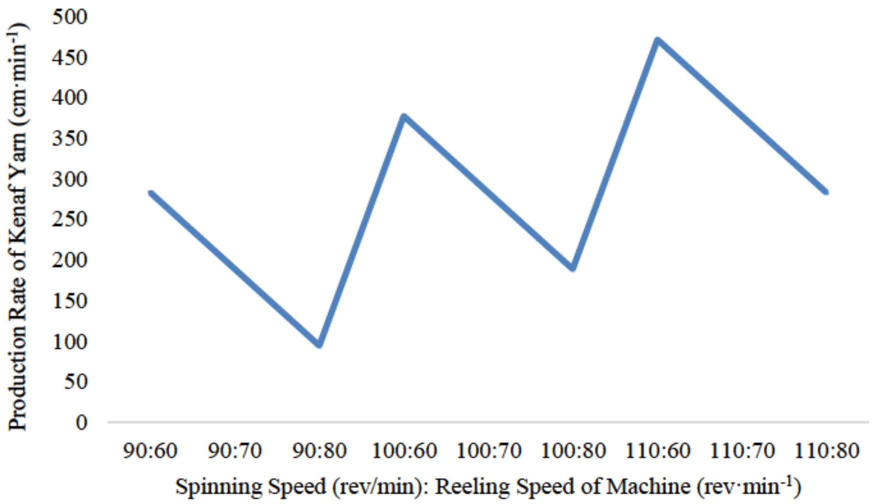


Figure 5. Production rate of Yarn at different Spinning and Reeling Speeds Combination

Table 2.
ANOVA for machine production rate values

Sourc	DF	SS	MS	Pr > F
Reeling Speed	2	1620.90	810.45	<.0001
Spinning Speed	2	802.23	401.11	<.0001
Spinning _*Reeling Speed	4	10.91	2.73	<.0001

Table 3.
Separation of machine efficiency means by DMRT for reeling and spinning speeds

Process	Speed (rev·min^{-1})	Mean Machine Efficiency*
Reeling	80	75.92^{a}
	70	66.43^{b}
	60	56.94^{c}
Spinning	90	73.31^{a}
	100	65.98^{b}
	110	59.98^{c}

* Superscripts with the same letters along each process are not significantly different at $p \leq 0.05$.

Level of twist at the highest efficiency of the machine

The machine spun kenaf fibre into yarn at different levels of twists, and the results (as in Table 1) shows that at the highest efficiency of the machine, the level of twists is 95.5 tpm, which is the highest of the range of 23.3-95.5 tpm. At 95.5 tpm, the machine twisted the fibres more to produce quality yarn at its highest efficiency which is lower than the twist standard for cotton that has a twist level range of 340-420 tpm (Chalachew, 2014). The determined level of twist could be used for related fibres and not limited to the use of this machine if the quality of spun yarn is acceptable to any desired or particular application. This also implies that with any deviation from the 95.5 tpm level of twist for kenaf fibres, the yarn strength will increase to a maximum and later decrease with the length of the yarn causing deformation and hence reducing the quality of output (Chalachew, 2014).

Conclusions

The performance evaluation of a spun yarn technology for small-scale kenaf farmers and processors was carried out in this study. It could be concluded from the result of the study that:

1. The spinning and reeling speeds have a significant effect on the production rate and formation of spun yarn.
2. Also, it was discovered that the machine produced at the highest efficiency at the spinning and reeling speeds combination of 90 and 80 $rev \cdot min^{-1}$ with the level of twist of 95.5 tpm which can serve as a guide or baseline to produce yarn from different varieties and subjected to quality ratio test.
3. It will be further required to automate the feeding mechanism of this machine and very important that end users comply to the recommendations of spinning speed and reeling speed combination to use this machine for the purpose of spinning kenaf fibres.

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ROZWÓJ I OCENA WYDAJNOŚCI MOTARKI I PRZĘDZARKI DO WŁÓKNA KETMII KONOPIOWATEJ

Streszczenie. Niniejsza praca przedstawia ocenę małej motarki i przędzarki do włókna kenafu. Urządzenie to wykorzystuje zasadę techniki przędzenia obrączkowego w celu wyprodukowania przędzy kenaf (jedno lub dwuwarstwowej). W skład maszyny wchodzą dwa silniki elektryczne 0.5 kW zamontowane na stalowej ramie 640x433x10mm (o prędkości silników kontrolowanej przez napęd 0.5 kW o zmiennej częstotliwości), wrzeciono, wlot, wałek podający, wałki przędzące, łożyska, przekładnie stożkowe. Maszynę oceniono przy zastosowaniu rożnych prędkości motkowania (90, 100 oraz 110 rpm), przędzenia (60, 70 oraz 80 obr$\cdot$min^{-1}) oraz próbki kenafu (Ifeken DI 400). Przy prędkościach motkowania i przędzenia 90 i 80 obr$\cdot$min^{-1}, opracowana maszyna mogła wyprodukować ciągłą długość przędzy kenaf skręconej przy 95,5 obrotach na minutę przy prędkości produkcji 0,94 m$\cdot$min^{-1} przy najwyższej wydajności (88,9%) maszyny. Poziom skręcenia przędzy podaje informację o wymaganym poziomie skręcenia dla włókna kenafu, ponieważ odkryto, że odchylenie od tej wartości powoduje deformację przędzy. To urządzenie było w stanie zmniejszyć trudności w produkcji przędzy kenaf i oczekuje się, że technologia pozytywnie wpłynie na wzrost kenafu i jego użytkowanie w Nigerii.

Słowa kluczowe: kenaf, włókno kenafu, motarka, technologia motkowania, urządzenie motkujące i przędzące