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Study and Design of a Stick Yam Slicer

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ABSTRACT

Agricultural transformation appears to be an excellent way to reduce post-harvest losses. This article discusses the study and design of a motorized yam stick slicer to facilitate slicing during processing of yam in processing units. After the field investigations, force was found that all the yam processors encountered still manually slice the yams before frying them. This state of choice therefore calls into question the difficulties encountered in the process of transforming said tuber. Laboratory tests and equipment studies have made it possible to mechanize the slicing step in the processing process. The results obtained led to the design of a motorized slicer model. Indeed, the absence of suitable equipment for slicing forces the processors to use the growing method as well as the difficulties they encounter during processing and this fact does not allow the production of fried yams to be recorded. The results of this study will make it possible to slice yams in record time and to have very precise sizes of sticks in order to increase the productivity of processors, which will have a positive impact on their economy.

KEYWORDS: Yam tubers; Yam processing; Manual yam slicer; Motorized yam slicer; Productivity growth.

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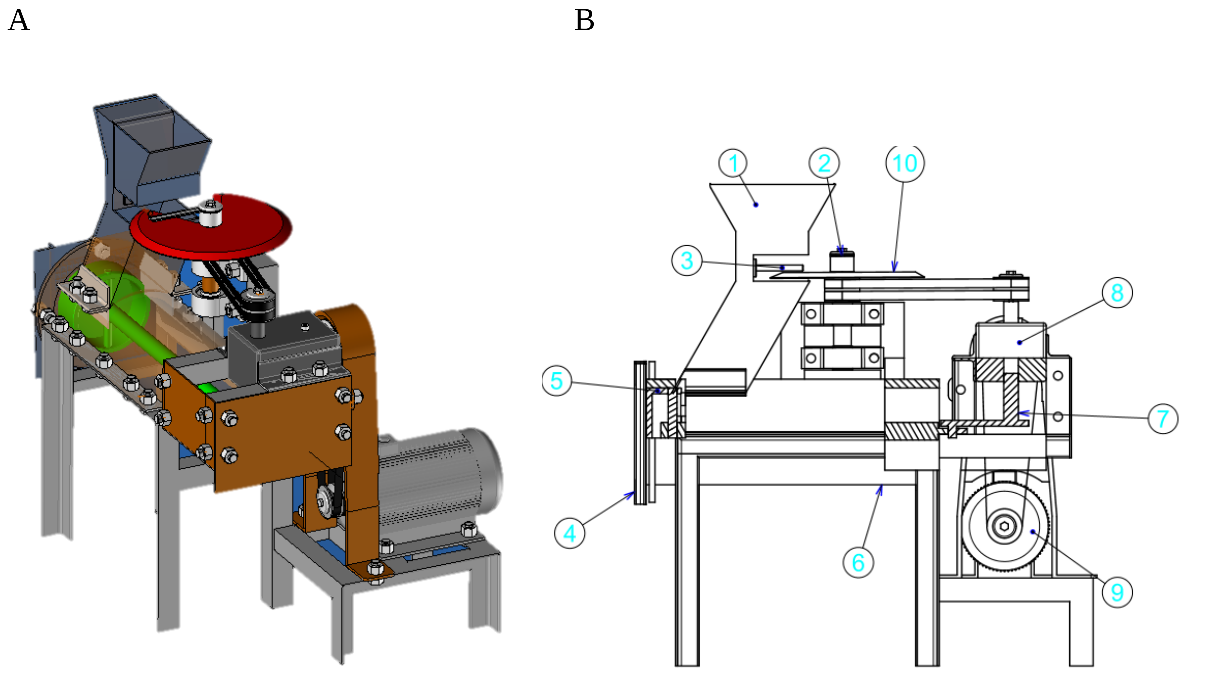
1. INTRODUCTION

The development of our country Benin is based on its agriculture. Agricultural mechanization is the introduction of machinery to reduce the drudgery and increase the productivity of agricultural processing [1]. Agriculture is the main source of wealth in Benin. The agricultural sectors constitute the most important sectors of the Beninese economy. Agriculture contributes 32.7% on average to GDP, 75% to export earnings, 15% to state revenue and provides about 70% of jobs [2]. It also and above all contributes to ensuring the country's food security. Agriculture is herefore called upon to play a driving role in development [2]. Faced with the global context marked by the rise in the prices of agricultural products, the Beninese state has made food sovereignty a major concern. There are 4.8 million hectares of arable land of which barely un million hectares, or 21%, is cultivated by around 400,000 farmers [3]. But because of the problems facing the sector, Benin adopted in its 2010 Strategic Plan for the Revival of the Agricultural Sector, the diversification of the agricultural sector with the promotion of other export crops, including yam, in the center and the north of the country [4]. Yam is a starchy product of great food importance in West Africa, commonly known as the yam belt, where more than 90% of world production is concentrated. In Benin, it is widely cultivated in the center and in the north and is part of the basic diet of the population after cassava with 72.4 kg / inhabitant / year [5]. The post-harvest losses of yam tubers recorded in producing countries in West Africa are very significant (40-50% after 6 months of storage). These losses are due to the lack of appropriate means and methods of conservation. The transformation of tubers into stable products (chips, flour) is a solution to preserving fresh yam. This technique also allows the weight of the material to be transported to be reduced by more than half [6]. Much research work has been done in the context of tuber slicing such as the sizing of a tuber slicer integrated into the value chain of chips by Lingani Abel Kader Hounsouho, Ye Sidouba Georges and Kam Sié in 2021, the realization in 1999 sticks with a tuber slicer, handcrafted by the CERNA-FSA-BENIN laboratory and the tuber cutter developed by the SONGHAÏ center. For all this works, the processing of the yam remains manual. In order to make our contribution to agricultural development in general and to the development of yam in particular, with the aim of increasing the productivity of yam processors, our choice fell on the study and design a motorized yam slicer.

2. MATERIAL AND METHOD

2.1 Specification of the designed machine

Figure 1 is a 3D and 2D drawing of the slicer designed in the Top Solid environment.



(1): Screw conveyor; (2): Knife; (3): Scraper; (4): Blade set; (5): Piston; (6): Cylinder; (7): Crank; (8): Gearbox; (9): Motor; (10): Plate.

Figure 1: Representation of the slicer: (A) Block diagram of the slicer, (B) Plan drawing of the slicer

The main components of the machine are the crank-crank system, the plate, the blade set, the knife, the cylinder and the frame.

- Connecting rod-crank system :

It transforms the rotation movement it receives from the reducer into a back and forth movement and pushes the yam slices against the blade set thanks to the piston it carries at the end.

- Tray:

This is the part of the equipment on which the yams sent to the hopper rest. It is cut in a pie shape to allow the yam slices to fall into the cylinder.

- Blade set:

It carries meshes that allow the yams to be sliced into sticks.

- Knife:

It is used to pre-slice the yams sent into the hopper.

- Frame :

It maintains in constant relative position the main active elements of the equipment.

2.2 Operating principale

When the motor (9) is started, it transmits a rotational movement to the reducer (8) by means of a power transmission system with a belt pulley. The (8) which receives this movement reduces its speed and transmits it in turn to the axis of the plate (V) and to the crank (7). The (V) sets in motion the plate (10) and the knife (2) which are integral to it, which allows to carry out a pre-slicing of yams which will be sent in the hopper (1) after the starting of the (9). The pre-sliced yams will fall into the cylinder (6). The movement that receives (7) is transformed into a back and forth movement thanks to the connecting rod system (IV) that carries at the end a piston (5), which pushes the yams inside the (6) green a set of blade (4). The yam pushed against the (4) will pass through the meshes and come out as a stick where they will be recovered.

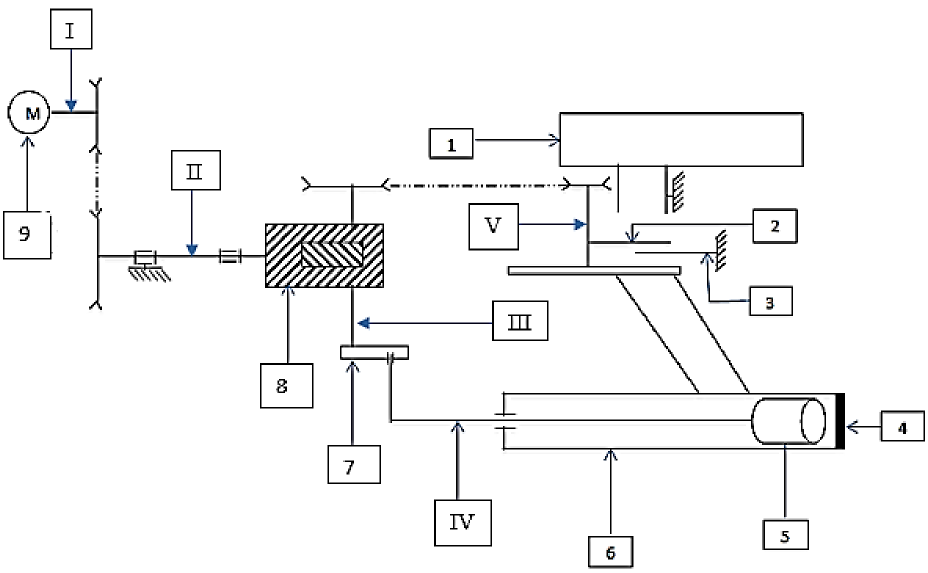


Figure 2: Kinematic diagram of the slicer

1 - Hopper;
2 - Knife;
3 - Wiper;
4 - Blade set;
5 - Piston;
6 - Cylinder;
7 - Crank;
8 - Gearbox;
9 - Motor;
10 – Plate;

I - Motor shaft;
II - Driven pulley shaft;
III - Gearbox shaft;
IV - Connecting rod;
V - Plate shaft

2.3 Modeling

This section is dedicated to the identification of mathematical models related to the different components of the slicer. These models reflect the physical phenomena that control the operation of the components.

2.3.1 Assembly of the slicer

The basic parameters of the slicer are the cutting force of the yams, the speed of the piston, the speed of rotation of the plate, the power and the useful torque of the unit.

In order to determine the cutting force of the yam, a shear test was conducted in the EPAC laboratory. The shear was performed in two directions: perpendicular and parallel to the yam fibers.

- Cutting force of the knife

It is necessary to keep the average value of the forces obtained in the yam shear test for the knife.

$$F_e = 30N \quad (1)$$

- Cutting force of the blade set

It was decided to multiply the maximum number of meshes (60 meshes) used to cut the yams in stick form by the average force value obtained in the shear test.

$$F_j = F_e \times 60 \quad (2)$$

- Piston advance speed

Piston advance speed is the stroke of the piston over the time it takes to make its forward and return stroke [7].

$$V_{Pis} = \frac{L_P}{t} \quad (3)$$

With V_{Pis} the speed of advance of the piston, L_P the stroke of the piston and t its put to make the stroke and return [8].

- Speed of rotation of the plate [9]

$$N_V \geq \sqrt{\frac{6(F_t * d_i)}{m_V * L^2}} \quad (4)$$

- Power output of the unit

The power output is equal to the power required by the table shaft and the crank system to slice the product.

$$P_u = P_{Man} + P_{III} \tag{5}$$

With P_u the useful power, P_{Man} the power of the crank and P_{III} the power of the plate shaft.

2.4 Drive chain

The drive chain consists of several types of transmissions that convert the engine power and determine the speed required for normal operation of the equipment. It is characterized by two parameters: total efficiency and transmission ratio. The type of transmission used here is the pulley-belt transmission.

2.4.1 Overall efficiency

The overall efficiency of the slicer is determined as follows:

$$n_g = \eta_{pal}^3 * \eta_{cou} * \eta_{cam} * \eta_{vis} \tag{6}$$

n_{pal}: Efficiency of the transmission by pair of bearings;

n_{cou}: Efficiency of the transmission by belt;

n_{cam} : Efficiency of the transmission by sliding crankpin;

n_{vis}: Efficiency of "worm and wheel" type gearing;

2.4.2 Transmission ratio

The transmission ratio is determined by:

$$r = \frac{D}{d} = \frac{N_m}{N_u} \tag{7}$$

D and d are the diameters of the driven and small driving pulleys in mm; N_m and N_u are the rotational speeds of the driving and small driven pulleys in tr/min, respectively.

2.5 Motor

The motor is the element that provides energy to the mechanism. It is characterized by its power and speed of rotation. These parameters are of decisive importance for the selection of the appropriate motor for the slicer.

2.5.1 Motor power

It is determined by the expression:

From (8) we derive P_m :

$$P_{m^x} = \frac{P_u}{n_g} \tag{9}$$

With $n_g$the overall efficiency, P_m the driving power.

2.5.2 Motor rotation speed

$$N_m^* = \frac{N_u}{n_g} \tag{10}$$

2.6 Mrive shafts

Two shafts are required for the proper operation of the drive train. The parameters of the drive system are power, speed and torque on each shaft. Therefore:

$$C = \frac{30 \times P}{\pi \times N} \tag{11}$$

2.7 Mizing of the belts

The transmission of motion from the motor to the other components will be done by the V-belt. The belt is characterized by its cross section, center distance, winding angle and maximum power rating.

2.7.1 Selection of the belt section

The belt selection depends on the operating power P_s and the speed of the drive pulley. The expression for the operating power is:

$$P_S = K_s * P_{m^x} \tag{12}$$

K_s is the service factor, which depends on the type of component, motor, receiver and daily operating time, and P_{m^x} is the motor power. Knowing the values of P_{m^x} and N_{m^x}, we refer to the transmission power range diagram of the belt type to select the belt type.

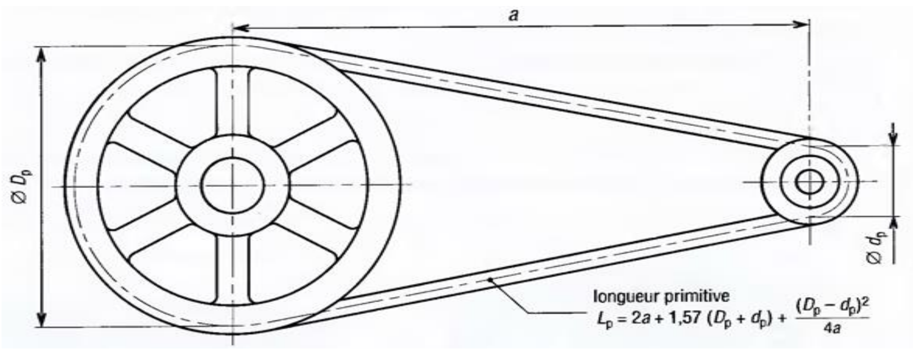


Figure 3: Primitive line of a V-belt [10]

2.7.2 Calculation of the belt center distance

The center distance of the belt is the distance between the axes of the two pulleys. In order to determine the theoretical center distance e, its minimum value (e_{min}) and maximum value (e_{max}) must first be determined.

When the ratio $\frac{D}{d}$ is between 1 and 3 (as in the present case), (e_{min}) and (e_{max}) are determined by the relationships (13) and (14) below.

With D and d d being the pitch diameters of the driven and driving pulleys respectively:

$$e_{min} = \frac{d+D}{2} + D \tag{13}$$

$$e_{max} = 3(d + D) \tag{14}$$

After determining e_{min} and e_{max}an approximate value of the theoretical center distance is chosen such that $e_{min} \leq e < e_{max}$.

With the axes of the pulleys parallel and the belt uncrossed, the theoretical length L_{th} of the belt is written:

$$L = 2e + \frac{\pi}{2}(D + d) + \frac{(D+d)^2}{4e} \tag{15}$$

After the calculation of L, the table with indicative pitch lengths of belts is used to select a standard length which is an approximation of the calculated theoretical length.

From the standard length, the actual center distance is then calculated as follows:

$$e_r = \frac{L-\frac{\pi}{2}(D+d)}{2} - \frac{(D+d)^2}{4\left[L-\frac{\pi}{2}(D+d)\right]} \tag{16}$$

2.7.3 Calculation of the basic power P_o

The basic power P_b is a function of the linear speed V_c and the diameter d of the driving pulley. V_c is expressed by [11]:

$$V_c = \frac{\pi N_m^*}{30}\left(\frac{d}{2}\right) \tag{17}$$

From the table representing the basic power P_b of the conventional V-belt, P_b is selected and V_c calculated.

2.7.4 Calculation of the winding angle θ

The winding angle is the angular difference between the direction of the belt and the horizontal direction. It is determined by the following formula:

$$\theta = 180 - 2\sin^{-1}\left[\frac{D+d}{2e_r}\right] \quad (18)$$

2.7.5 Calculation of the admissible power P_a

The permissible power P_a is determined as follows [12]:

$$P_a = P_b * K_L * K_\theta \quad (19)$$

With K_θ the correction coefficient as a function of the winding angle θ and K_L the correction coefficient as a function of the length L.

2.7.6 Calculation of the number of belts n_{co}

The number is determined by the quotient of the operating power and the permissible power.

$$n_{co} = \frac{P_s}{P_a} \quad (20)$$

2.7.7 Pulleys

The system to be designed consists of four (04) pulleys of different diameters, three of which have the same diameter. The parameters taken into account by the pulleys are the weight and the forces exerted by the pulleys on the belts.

2.7.8 Weight of the pulleys

The pulleys are made of aluminum alloys. Let $\rho_{AL} = 2{,}7\ kg/dm^3$, be the density of the pulleys and P_p the weight of the pulley. Assume that the pulleys are cylindrical without dimples with diameter d and height equal to the thickness b of the pulley. The weight can be determined by the formula [13]:

$$p_p = \rho_{AL} * g * \frac{d^2 * \pi * b}{4} \quad (21)$$

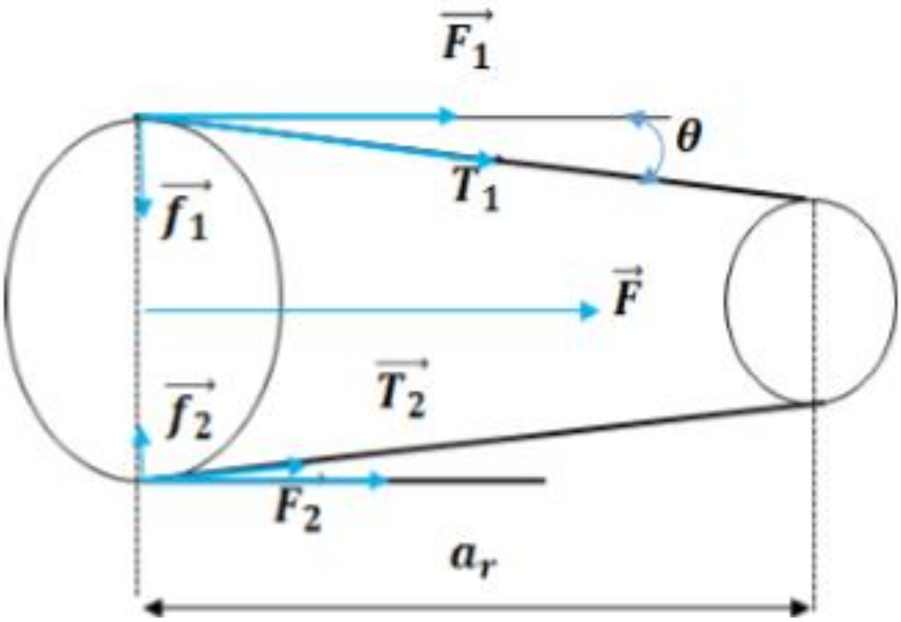


Figure 4: Tension forces [10]

2.7.9 Operating tension forces of the belts

The belt connecting the two pulleys allows for both taut and soft strands. T_1 is the tension in the taut strand and T_2 is the tension in the soft strand. T_1 and T_2 are subject to the following relationships [14]:

$$T_1 - T_2 = \frac{2\times C_M}{D} \tag{22}$$

$$\frac{T_1}{T_2} = e^{f\theta} \tag{23}$$

From these two voltages, we obtain the installation voltage

$$T = \frac{1}{2}(T_1 + T_2) \tag{24}$$

The forces exerting the torque F_{py} along the horizontal and F_{pz} along the vertical are then determined such that :

$$F_{py} = 2n_{co}T \sin\beta \tag{25}$$

$$F_{pz} = 2n_{co}T \cos\beta \tag{26}$$

With

$$\beta = \arcsin\frac{R-r}{e} \tag{27}$$

R *and* r being respectively the radii of the driven and driving pulleys and e the actual center distance.

2.7.10 Shaft diameter

In normal operation, the drive shafts are subjected to bending, torsion and shearing. Conditions must be met for their strength [11].

Resistance to bending

$$\tau_t \leq R_{pg}$$

$$d \geq \sqrt[3]{\frac{32M}{\pi\sigma_{adm}}} \qquad (28)$$

Resistance to shear

$$\sigma_f \leq R_p$$

$$d \geq \sqrt{\frac{4T_{max}}{\pi R_{pg}}} \qquad (29)$$

Resistance to torsion

$$\tau_c \leq R_{pg}$$

$$d \geq \sqrt[3]{\frac{16C_m}{\pi R_{pg}}} \qquad (30)$$

With M the maximum bending moment, T_{max} the maximum shear force, C_m the maximum torque on the shaft and R_{pg} the practical slip resistance of the steel used for the shaft.

To calculate the diameter in all three cases, the standard diameter immediately above the value of the largest of the three is selected.

2.8 Estimating the cost of the trencher

The overall cost (Cg) of the machine will be estimated according to the cost (Cm) of the materials used and the cost (Cu) of machining the parts.

That is to say:

Cg = Cm + Cu (31)

3 RESULTS AND ANALYSIS

3.1 Results

The results of the applications of the different mathematical models are reported in Tables 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 and the overall cost of the slicer in Table 11.

Table 1: Values of the characteristic parameters of the crank-crank system

Components	Parameters				
connecting rod	Length (mm)	diameter (mm)	Linear speed ω_0 (m/s)	Pushing force (N)	Power (W)
	522.5	30	0.23	1800	414
crank	Length (mm)	width (mm)			
	150	110			
piston	Length (mm)	diameter (mm)			
	60	150			

Table 2: Values of the characteristic parameters of the knife

Components	Parameters				
Knife	Length (mm)	width (mm)	Speed of rotation $(\boldsymbol{tr/min})$	Cutting force (N)	Power (W)
	135	20	25	30	85,77

Table 3: Values of the characteristic parameters of the transmission chain

Components	Parameters			
Drive chain	Efficiency			Transmission ratio
	Bearing (η_{pal})	Connecting rod-crank (η_{cam})	Belt (η_{cou})	0,25
	0,99	0,5	0,98	
	Global efficiency			
	0,45			

Table 4: Values of the characteristic parameters of the motor

Components	Parameters	
Motor	Power P_{m^x}(KW)	Speed of rotation N_{m^x} (tr/min)
	1,5	1000

Table 5: Values of the characteristic parameters of the trees

Components	Parameters		
	Power (kW)	Speed of rotation (tr/min)	Torque $(N.m)$
Shaft I	1,5	1000	14,32
Shaft II	1,47	250	14,32
Shaft III	1,43	25	56,15
Shaft IV	1,43	25	546,22
Shaft V	1,28	25	698,46

Table 6: Values of the characteristic parameters of the pulleys

Components	Parameters			
Motor pulleys	Weight of the driving pulley	Weight of driven pulley	Forces exerting the torque	
	$\mathbf{p_{pm}} = 2{,}12$ N	$p_{II} = 33{,}93$ N	$F_{py} = 18{,}57$ N	$F_{pz} = 99{,}93$ N
Plate pulleys	$\mathbf{p_{III}} = 2{,}12$ N	$p_V = 2{,}12$ N	$F_{py} = 0$ N	$F_{pz} = 827.02$ N

Table 7: Values of the characteristic parameters of the drive belt

Components	**Parameters**			
Motor pulleys	Operating power P_s (en kW)	Linear speed v_s (en m/s)	Center distance (en mm)	
	2,1	2,62	$e_{min} = 175$	$e_{maxi} = 500$
			Theoretical center distance (mm) $e = 400$	
			Actual center distance (mm) $e_r = 410{,}42$	
Plate pulleys	Puissance de service P_s (en kW)	Vitesse linéaire v (en m/s)	Center distance (en mm)	
	2,02	0,26	$e_{min} = 950$	$e_{maxi} = 1000$
			Theoretical center distance (mm) $e = 900$	
			Actual center distance (mm) $e_r = 914{,}47$	

Table 8: Values of characteristic power transmission parameters of the belt

Components	**Parameters**				
Motor pulleys	Standard length L (mm)	Belt wrap angle θ	Basic power P_b (en kW)	Permitted power P_a (en kW)	Number of belts
	1250	210,06°	1,54	1,30	2
Plate pulleys	2500	180°	1,11	1,11	2

Table 9: Values of the characteristic parameters of the drive shafts

Components	Parameters			
	Maximum torque C (en N.m)	Maximum shear force T_{max} (en N)	Maximum bending moment M (en N.m)	Practical slip resistance R_{pg}(en MPa)
Shaft IV	546,22	72561,33	621,28	124,25
Shaft V	698,46	558876,8	278,56	124,25

Table 10: Values of the characteristic parameters of the drive shafts

<table>
<tr><th rowspan="2">Components</th><th colspan="4">Parameters</th></tr>
<tr><th colspan="3">diameter d (en mm)</th><th>length L (en mm)</th></tr>
<tr><td></td><td>Resistance to bending</td><td>Shear strength</td><td>Resistance to torsion</td><td rowspan="3">522,5</td></tr>
<tr><td rowspan="2">Shaft IV</td><td rowspan="2">≥ 19,32</td><td>≥ 13,56</td><td>≥ 15,16</td></tr>
<tr><td colspan="2">Selected diameter (en mm)
25</td></tr>
<tr><td rowspan="2">Shaft V</td><td rowspan="2">≥ 23,7</td><td>≥ 10,67</td><td>≥ 17,44</td><td rowspan="2">198,41</td></tr>
<tr><td colspan="2">Selected diameter (en mm)
30</td></tr>
</table>

Table 11: Cost of the trencher

Cost of materials ($)	Turning labor ($)	Welding labor ($)	Total cost ($)
465,89	88,1	52,86	606,5

3.2 Analysis of the results

3.2.1 The engine

The required characteristics of the slicer motor are as follows: $P_m = 1{,}12771 kW$ and speed N_m = 25 tr/min. For safety reasons and because the value found does not appear in the standard range of motor characteristics, a motor with a power immediately higher than the calculated value is used. After consulting the motor catalog, the LP 90L motor with power $P_{m^x} = 1{,}5\ KW$ and speed N_{m^x} = 1000 tr/min was selected [12].

3.2.2 Drive shaft

The results of the calculations show that the connecting rod should use a shaft with diameter $d = 25\ mm$ and the plate should use a shaft with diameter $d = 30\ mm$.

3.2.3 The allowable power of the belt

According to the table showing the basic power P_b (KW) of conventional V-belts, the diameter of the small pulley chosen is not directly suitable for a basic power. The basic power corresponding to the diameter of the small pulley was first determined by an interpolation method. Then, by the same method, the basic power corresponding to the linear speed of the belt was determined.

3.2.4 Total cost of the machine

The cost of the equipment is estimated at 606,5 $. Given the purchasing power of a rural household in Benin, yam processors will not be able to afford such a slicer. The government should support processors through subsidies.

4 CONCLUSION

Agriculture is therefore called upon to play a driving role in development. Faced with a global context marked by rising prices for agricultural products, the Beninese state has made food sovereignty a major concern. However, due to the problems in the sector, Benin has adopted in its Strategic Plan for the Recovery of the Agricultural Sector, the diversification of the agricultural sector with the promotion of other export crops, including yams. This study allowed the design and estimation of the yam slicer. This equipment has a good working precision and is ergonomic. However, the realization of a model and full-scale tests will make it possible to evaluate the technical and economic performance of the yam slicer and to improve it at the same time. The realization of this particular piece of equipment should bring considerable socio-economic benefits to the manufacturers and in general will open up many business opportunities.

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