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Development and performance evaluation of a low-cost paper egg tray making machine

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ABSTRACT

Chicken eggs are extremely fragile and require protective packaging for handling, storage and delivery. Paper egg tray, the most globally acceptable package for eggs, is often imported, costly and scarce in Nigeria due to difficulties in procurement and management of standard machines for trays' local production. Therefore, this study was intended to locally develop and evaluate the performance of a low-cost paper egg tray-making machine to ease the local production and distribution of paper egg trays in Nigeria. Using metal scraps as construction materials and a sand-casting method for mould manufacture, a 30-cell paper egg tray-making machine was developed, and its performance was evaluated. Power rating determination of the machine was done using Logger Interface Program. The paper egg trays having dimensions of 300 × 300mm; cell diameter of 35mm; cell depth of 25mm; and wet and dry weights of 298.0 g and 86.0 g, respectively, were produced. The vibration resistance of the manufactured trays was compared with existing oness at a frequency of 5 Hz. The machine of 1.4 Kw power rating and sand-cast aluminum-alloy moulds was developed at a total cost of N76, 720 ($210). The machine could be operated manually with a minimum of one employee, using reciprocating mould movement at a capacity of ten trays per hour. An acceptable paper egg tray was obtained with Chipboard (65.0%) and Newsprint (35.0%) wastepaper mix, fabric-mesh hole-size of $\leq$ 0.6 mm and pulp slurry of 4.0% consistency. The vibration resistance result showed that the egg failure by the manufactured and existing paper egg trays was moderate and comparable. The machine development could encourage waste management, youth employment, and affordable local paper egg tray manufacture and supply in Nigeria.

Introduction

Chicken eggs are essential food for all ages and are naturally packaged and protected for human benefits. They are consumed worldwide; their high nutrient content, low caloric value and ease of digestibility complement their therapeutic importance for adults [1–5]. However, eggs are fragile irrespective of their relative strength, and care must be taken to avert economic losses due to shell breakage. Packaging of eggs is essential as it entirely protects the eggs from micro-organisms, such as bacteria; natural predators; loss of moisture; tainting; temperatures that cause deterioration; restricting

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gas exchange through the shell and shell membrane and possible crushing while being handled, stored or transported [2]. Also, they are naturally breakable and require careful handling and protection, especially during supply sequence. Eggs are transported through long distances starting from the farm through packers, wholesalers, retailers, depots, supermarkets, and finally to the consumer; yet they must be intact, fresh and attractive [4,5].

The short supply of eggs is attributed to the hitches in safe packaging and transportation to destinations, especially the far Northern part of Nigeria. The southern part of Nigeria has favourable weather conditions for poultry farming. Eggs are produced in large quantities, and the bulk of these eggs are usually transported to the Northern part of the country and its neighbourhood like Chad, Niger, Mali and others [6–9].

Nigeria faces the challenge of qualitative and quantitative supply of paper egg trays. The incursion of various imported brands of PET into the market is compounding the problem. Many paper egg tray-producing companies in the country have gone into bankruptcy primarily due to complexity in the procurement and maintenance of gigantic, expensive, imported and standard PET-making machines and their accessories [10–12]. The inadequate supplies of eggs to remote destinations where there is more need and demands are connected to scanty production and supplies of paper egg trays believed to be the most acceptable, affordable and safest packaging items for poultry eggs. The scanty local production of trays is hinged on the hassles of the procurement of conventional machines, their maintenance, repairs and other factors. The trend may continue if reliance on foreign industrial machines continues unabated. Local production of essential and necessary equipment for industrial and domestic use is usually the way forward in Africa, as found in several scientific reports [13–16]. Therefore, there is an urgent need to look inward to produce machines capable of producing paper egg trays.

Researchers have made several attempts to ensure local development of paper egg tray-making machines to ease local production and distribution of egg-packaging trays. According to Onilude [12], a machine capable of producing 30-cell paper egg trays was developed using the technology involving forming mould being lowered into the pulp vat. Then, the slurry was shaped on the mould using a vacuum thrust that sucks in both the fibre and water. In the end, a paper egg tray was formed, having 30 cavities for egg packaging. Although the machine's development provides valuable data on the paper egg tray machine and its production procedure, some more vital information is required for a subsequent hitch-free replication of the design, fabrication, and tray production procedures.

In the report, the mould used for the machine was made from a pre-perforated iron sheet of unknown mechanical strength and other mould parameters. Moulds for PET production must be corrosion resistant and meet specific strength standards for adequate efficiency and durability. Also, the vacuum suction rating of the water pump used needs to be stated for future reference. The slurry parameters like the types and mixing ratio of the waste paper used are not reported. The pulp consistency of 5% used may not conform with the conventional standard for PET production; a lower consistency (1-2%) is being practised globally. Drying duration and post-drying properties of the trays were not reported; likewise, the tray parameters like mechanical and physical properties of the trays. Also, the general properties like dimensions and other tray features were missing in the report. All the facts mentioned above are required to guide future replication and improvement of the machine. Moreover, these must be considered by subsequent researchers and PET-making machine designers.

Given the preceding, this work was designed to develop and evaluate the performance of a machine, made from the available metal scraps, capable of manufacturing 30-cell paper egg trays from waste papers to ease local production and distribution of trays, employ youths, and promote environmental sanitation.

Materials and method

Description of the machine

There were three machine segments, which included frame, moulding section, and vacuum suction Fig. 1. As shown in item 7 of Fig. 1, the frame comprises the four steel columns welded with one foot by one-foot square frame as a base, giving the machine stability. The four steel columns which stand opposite one another accommodate one compression spring each. The machine columns were made of mild steel (rod) of 18mm diameter and 300 mm length. The base was a square frame made of mild steel square pipe of dimension 25 mm x 25 mm, having lengths of 300 mm each. Also, the stock vat (also known as pulp vat) is a 900 mm diameter steel container of 600 mm depth, 2.5 mm thickness and overall weight of 7.2 kg, serving as storage for the ready stock.

The moulding system consists of a forming mould, a lower vacuum chamber and the presser. The forming mould is a machined aluminum cast of about 5 kg weight, 10mm thickness, and 300 mm by 300 mm dimensions, having a yield strength of 55 MPa, Ultimate tensile strength of 62 MPa, Young's modulus of 68.9 GPa, Poisson's ratio of 0.33 ul and Shear Modulus of 25.9023 GPa. It, however, has 30 cells in total with 3mm-diameter holes perforated through it. Each cell has a diameter of 38 mm, depth of 25 mm and crest height of 25 mm. Moreover, the vacuum chamber is made of a metal sheet of 2 mm thickness and shaped in a parabolic structure to accommodate the forming mould. Also, the presser is made of two 10 mm diameter steel rods of 450 mm length, each connected by an 18mm diameter steel round pipe of 300mm length serving as the beam. The lower vacuum chamber and the presser jointly weighed 5 kg. The de-moulding unit consists of transfer mould and an upper vacuum chamber attached and resting on the frame columns. The transfer mould had the same attributes as forming mould, and both were designed to mesh. Also, the upper vacuum chamber was made of a 2.5 mm thick metal plate of rectangular shape, weighing 2 kg, and was screwed together with transfer mould.

S/N	PART NAME
1	Presser
2	Vacuum Chamber
3	Transfer/Counter Mould
4	Mould
5	Vacuum Chamber
6	Spring
7	Frame
8	Stock Vat
9	Hose
10	Vacuum Pump
11	Pipe with Valve

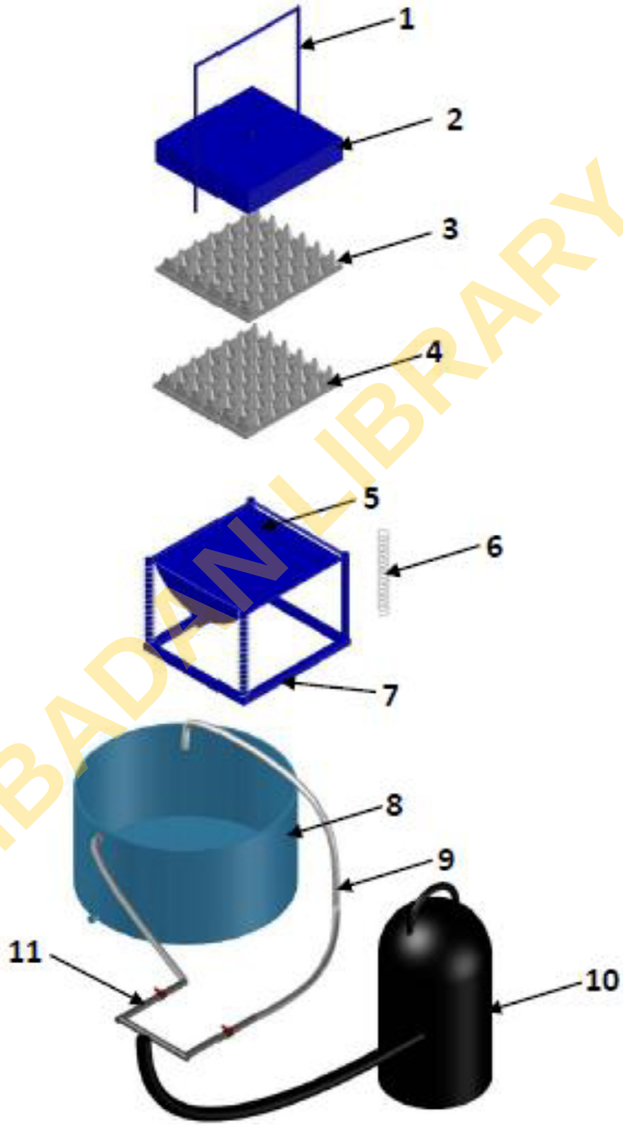

Fig. 1. Exploded View of the Paper Egg Tray Machine.

The vacuum pump selected was Hoover - a device that uses an air pump for creating, improving and maintaining a vacuum. A drum-type wet/dry cylindrical Hoover of 6.8kg weight, -20.5 kPa suction, 75 dB noise-level, 36 mm-diameter suction hose and 1250-watt input power was selected to serve the dual purposes of vacuum pressure creation and cleaning of the production environment. The suction regarding Hoover is the maximum pressure difference (margin) that the pump can create. The higher the suction rating of a hoover, the more powerful it is. In addition, Drum-types are heavy-duty engineering versions of cylinder vacuum. Wet and dry

Hoovers are a specific drum model used to clean up wet or liquid spills (Wikipedia, 2017). Therefore, the selected Hoover was expected to lower the internal pressure of the hose from standard atmospheric pressure (about 100 kPa) by 20.5 kPa. One inch of water is equal to about 249 Pa; therefore, the expected suction capacity of the Hoover was 82 inches (2,058 mm) of water.

Materials selection and design considerations

The materials selected for the fabrication of the machine were mild steel and aluminum alloy. Mild steel was used for the entire body and structure, while aluminum alloy was used to produce forming and transfer moulds. The choice of the metal categories was informed by their availability and suitability of their engineering (physical and mechanical) properties. In particular, steel was chosen based on its acceptable density, hardness, toughness, tensile strength, yield strength, corrosion resistance, fatigue strength, and malleability. In contrast, the aluminum alloy was chosen due to its suitable density, shear strength, yield strength, tensile strength, corrosion resistance, and thermal conductivity.

However, the parameters considered during the design and fabrications of the machine were efficiency, Safety, durability, economy, and ergonomics. The work input into the machine's running was protected against excess friction and weak machine parts contact to achieve the set design considerations. Sharp machine edges were ground, and joints were given appropriate welding for safe machine operation. For economical and maintenance reasons, materials of minimum dimensions and standard sizes were selected from the locally-available materials. Meanwhile, machine operation was made simple, machine height was made appropriate, and all repair-prone components were bolted for ease of repair and maintenance.

Design method and analysis of machine components

Design assumptions

The following assumptions were made throughout the design and development of the machine parts;

i The machine was designed to produce 30-cell paper egg trays of 300 mm x 3000 mm dimensions at a maximum of 4% pulp consistency
ii The materials for the machine construction were selected from high-quality scraps devoid of any physical or mechanical deformation.
iii The power rating of the whole machine should not exceed 1.4 KW.
iv The machine should be light, movable, and should not exceed 760 mm in height

Machine design considerations

The following factors were taken into consideration during the design and fabrication of the machine:

1 *Machine Efficiency:* Work input into the machine's running was protected by containing excess friction and weak machine parts contact.
2 *Safe Machine Operation:* Sharp edges of the machine were ground, and joints were given appropriate welding for safe machine operation.
3 *The durability of the Machine:* Materials of high strength and durability were selected during machine development.
4 *The economy of the Machine:* Materials of minimum dimensions and standard sizes were selected from the available scraps to reduce the cost of machine construction, maintenance and repair.
5 *Machine Operation:* Machine operation was made simple, machine height was made appropriate, and all repair-prone components were bolted for ease of repair and maintenance.
6 *Noise Pollution:* Noise-damping material (rubber) was incorporated to minimize the machine's operational-noise level to the barest minimum.

Analysis of machine components

The following parameters were considered, determined and designed for in the machine according to [17]:

i **Weight**

The weight of each constituent as well as the total machine weight was cautiously considered as follows:
Weight = mass x g

$$\text{Mass} = \frac{\text{density}}{\text{volume}} \tag{1}$$

Volume = Area x length,
Density of steel = 7850 kg/m^3 (Wikipedia, 2012)

i **Design of compression springs**

Four closed and ground compression springs were selected and attached along the length of the four columns (rods) supporting the egg-tray former to achieve appropriate spring seating. Each spring supported the 2.5 kg weight of the former and its content and had a deflection rate of 3 N/mm. Each spring was designed as follows: The rate of deflection of the spring is given as:

$$R = \frac{P}{f} \tag{2}$$

where R=rate of deflection=3 N/mm

P=applied load on the spring=2.5 kg=25 N f=difference between the spring free length and dead length

$$f = L_f - L_d \tag{3}$$

where L_f=free length of the spring

L_d = dead length ofthe spring

$\therefore f = \frac{P}{R} = \frac{25}{3} = 8.33$

Based on availability of springs in spare part markets, a spring of 250 mm free length and 240 mm dead length was chosen, giving a value of 10 mm for the difference between free length and dead length (i.e. $f = L_f - L_d = 250 - 240 = 10$ mm).

The selected spring haD a wire diameter of 2 mm and coil number of 24.

a **Solid Height of spring**

The solid height (H) of the spring is given as:

$$H = d(N_c + 2) \tag{4}$$

where d=diameter of spring wire=2 mm

N_c=number of coils=24

∴H=2(24+2)=52 mm

Thus, the solid height of the spring was 52 mm

a **Allowable load on the spring**

The maximum allowable load ($P_{allowable}$) that can be safely sustained by the spring is given as:

$$P_{allowable} = R(L_f - H) \tag{5}$$

$$P_{allowable} = 3(250 - 52)$$

$$= 3 \times 198 = 594N$$

Thus, the spring was safe under a load of 25N since the maximum allowable load it could sustain was 594 N.

a **Maximum shear stress**

The stress imposed on the spring coils as a result of the applied load is referred to as maximum shear stress, which is given as:

$$\mu_{max} = \frac{8\omega D}{\pi d^3} \times P \tag{6}$$

where μ_{max} = maximum shear stress in N/mm^2 ω=Nahl correction factor

D=mean diameter in mm d=wire diameter in mm

The mean diamter is given as:

$$D = D_{outer} - 2d \tag{7}$$

where D_{outer}=outer diameter of the spring

Based on spring measurement,

$$D_{outer} = 35mm$$

$$\therefore D = D_{outer} - 2d = 35 - 2(2)$$

$$D = 31mm$$

$$\text{Also,}\ \omega = \frac{4C - 1}{4C - 4} + \frac{0.615}{C}$$

where $C = \frac{D}{d} = \frac{31\text{ mm}}{2\text{ mm}} = 15.5$

$$\therefore \omega = \frac{4(15.5) - 1}{4(15.5) - 4} + \frac{0.615}{15.5} = 1.09$$

$$\text{Thus,}\ \mu_{max} = \frac{8\omega D}{\pi d^3} \times P = \frac{8 \times 1.09 \times 31}{\pi \times 2^3} \times 25$$

$$= 268.89N/mm^2$$

$$\cong 269N/mm^2$$

Therefore, the maximum shear stress of the spring when under loading was 269 MPa a **Number of active coils of the spring**

The number of coils that were actively supporting the load of 25 N was given by:

$$n = \frac{Gd^4}{8RD^3} \quad (8)$$

where; G=shear modulus of spring material

$= 3 \times 10^5 N/mm^2$ for mild steel $\therefore n = \frac{3 \times 10^5 \times 2^4}{8 \times 3 \times 31^3} = 6.71n \cong 7coils$

Thus, only 7 coils were actively supporting the load during working condition of the former.

i **Design of columns (rods)**

The forming section is supported on four columns (rods), each made of high-carbon steel and of length 300 mm. To design for the appropriate column diameter using Euler's formula, a value of 15 mm is assumed and tested for its safety under the system of loading.

Cross sectional area (A) of the column (rod) is given as:

$$A = \frac{\pi d^2}{4} \quad (9)$$

where d = diamter of the circular rod = 15 mm

$$A = \frac{\pi \times 15^2}{4} = 176.71\ mm^2$$

Moment of inertia (I) for the circular section of the rod is given as:

$$I = \frac{\pi d^4}{64} \quad (10)$$

$$= \frac{\pi \times 15^4}{64}$$

$$I = 2485.05\ mm^4$$

Radius of gyration (R) is given as:

$$R = \sqrt{\frac{I}{A}} \quad (11)$$

$$= \sqrt{\frac{2485.05}{176.71}}$$

$$R = 3.75\ mm$$

Slenderness ratio (S_r) for the rod was given as:

$$S_r = \frac{L_e}{R} \quad (12)$$

where L_e = effective length of the column

For an end condition where the column is fixed at one end (welded end) and hinged at the other end (anchored end), then;

$$L_e = 2L \quad (13)$$

where; L = length of the column = 300 mm$L_e = 2 \times 300 = 600$ mm

$$S_r = \frac{L_e}{R} \quad (14)$$

$$= \frac{600}{3.75} = 160$$

Since $S_r < 180$, therefore Johnson's straight line formula is applied to estimate the critical load that can be sustained by the column before failure occurs.

Johnson's straight line formula was given as:

$$P_{cr} = \sigma_y.A\left[1-\left(\frac{\sigma_y}{4\pi^2E}\right)\left(\frac{L_e}{R}\right)^2\right] \quad (15)$$

where; P_{cr} = critical load before failure occurs σ_y = yield strength in compression = 210 MPa (for mild steel)E = Young Modulus = 200GPa (for structural steel)A = cross sectional area = 176.71 mm^2 = 176.71 × $10^{-6}m^2$

$$\therefore P_{cr} = 210 \times 10^6 \times 176.71 \times 10^{-6}\left[1-\left(\frac{210 \times 10^6}{4 \times \pi^2 \times 200 \times 10^9}\right) \times 160^2\right]$$

$$P_{cr} = 25266.78\ N$$

$$\cong 25\ kN$$

Therefore, the total load that can lead to failure of the column is 25 kN.

The total weight of the presser on the columns (rods) is 7.5 kg (75 N), which was less than the critical load that can be sustained by the column. Thus, the column was safe under this loading condition.

i **Design of welded joints of the columns (Rod)**

Each of the load-carrying columns was welded with minimum size of weld and length of weld; and the maximum shear and maximum normal stresses borne at the joints were estimated as follows;

Throat thickness of weld, t = 3 mm
Leg or size of weld, s = 5 mm
Length of column (rod), l = 300 mm
Diameter of rod, D = 15mm
Applied load at the joint, $P = \frac{75}{4}N = 18.75\ N$

From the loading system, the joint is subjected to direct shear stress and bending stress,

$$\text{Throat area},\ A = t \times \pi D$$

$$= 0.707s \times \pi D$$

$$= 0.707 \times 5 \times \pi \times 15$$

$$= 166.58\ mm^2$$

Direct shear stress (τ) is given as:

$$\tau = \frac{P}{A} = \frac{18.75}{166.58} = 0.113N/mm^2$$

Bending moment (M) was given as:

$$M = P \times l = 18.75 \times 300$$

$$M = 5625Nmm$$

For a circular section, the section modulus was given as:

$$Z = \frac{\pi tD^2}{4} = \frac{\pi \times 0.707s \times D^2}{4}$$

$$= \frac{\pi \times 0.707 \times 5 \times 15^2}{4}$$

$$= 624.69Nmm^3$$

Therefore, bending stress (σ_b) was given as:

$$\sigma_b = \frac{M}{Z} = \frac{5625}{624.69} = 9.00\mathrm{N/mm}^2$$

$$= 9\mathrm{MPa}$$

The maximum normal stress, (σ_{max}) was given as:

$$\sigma_{max} = \frac{1}{2}\sigma_b + \frac{1}{2}\sqrt{\sigma_b + 4\tau^2} \tag{17}$$

$$= \frac{1}{2} \times 9 + \frac{1}{2}\sqrt{9^2 + 4 \times 0.113^2}$$

$$= 9.0014\mathrm{MPa}$$

$$\therefore \sigma_{max} = 9\mathrm{MPa}$$

Therefore, the maximum normal stress at the joint was 9 MPa.
The maximum shear stress (τ_{max}) at the joint was given as:

$$\tau_{max} = \frac{1}{2}\sqrt{{\sigma_b}^2 + 4\tau^2} \tag{18}$$

$$= \frac{1}{2}\sqrt{9^2 + 4 \times 0.113^2}$$

$$= 4.5014\mathrm{MPa}$$

$$= 4.5\mathrm{MPa}$$

Thus, the maximum shear stress at the joint was 4.5 MPa, i.e. half the maximum normal stress imposed at the joints.

i **Stock/pulp vat design**

Two different categories of tensile stresses were expected to be imposed on the stock/pulp vat (Fig. 2). The first was tensile stress acting in a direction tangential to the circumference of the vat (vertical or circumferential stress), and the second was tensile stress on a longitudinal section or the cylindrical walls of the vat (transverse stress) .

$$\mathrm{Verticaltensilestress}\ \delta_1 = \frac{P * d}{2 * t} \tag{19}$$

$$\mathrm{Transversetensilestress}\ \delta_2 = \frac{P * d}{4 * t} \tag{20}$$

$$\mathrm{MaximumShearstress}\ \tau = \left(\frac{\delta 1 - \delta 2}{2}\right) \tag{21}$$

Where;

P = internal pressure (N/mm^2) = ρ*g*h d = vessel diameter (375 mm) t = vessel thickness (2 mm) h = vessel height (600 mm)

ρ = density of the used fluid (1000 kg/m^3) g = acceleration due to gravity (9.81 m/s^2)

$\delta_1 = \frac{0.0059*375}{4} = 0.55$ N/mm^2= 0.55 MPa

$\delta_2 = \frac{0.0059*375}{8} = 0.28$ N/mm^2= 0.28 MPa

$\tau = \frac{0.55-0.28}{2} = 0.14$ N/mm^2= 0.14 MPa

The expected maximum shear stress on the vessel was 0.14 MPa

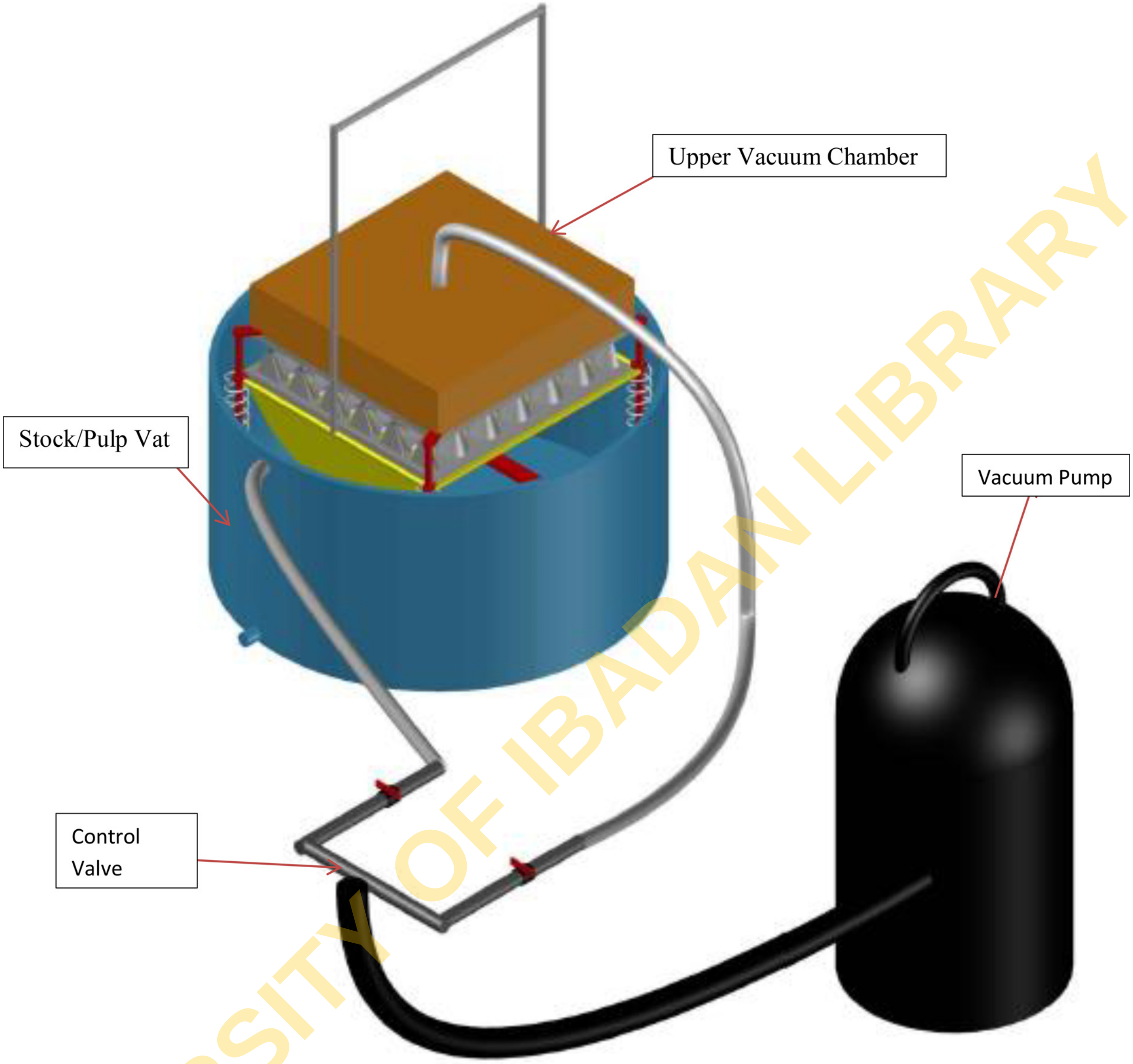

Fig. 2. Cottage Paper Egg Tray making Machine.

Mode of operation of the machine

Fig. 2 shows the paper egg tray-making machine. The machine is operated manually with only the electric Hoover. First, the slurry is prepared and transferred into the pulp vat, the lower vacuum chamber containing forming mould is immersed in it by pressing the handle downwards. Then, vacuum suction is applied through its reverse and will gradually attract the fibres in the slurry to the forming mould to form its shape. The forming mould will then be removed from the slurry vat while still under vacuum, which will allow water to be drained from the wet paper trays. Next, the wet tray formed will be absorbed by the transfer mould by releasing the handle and vacuum suction. Finally, the wet tray is ejected through compressed-air-blowing of the Hoover/ Vacuum pump. The control valve does vacuum suction and compressed-air-blowing interchange. The wet tray is then collected on a metallic sheet and sun-dried for about 12 h.

Trial production of paper egg trays

Fig. 3 shows the production flowchart of paper egg trays. The entire paper egg tray production activities can be performed in a 9 m^2 space. The machine moulds could be produced using sandcasting method which is common within Ibadan metropolis; and the complete machine fabrication could be done at any available welding shop within the community.

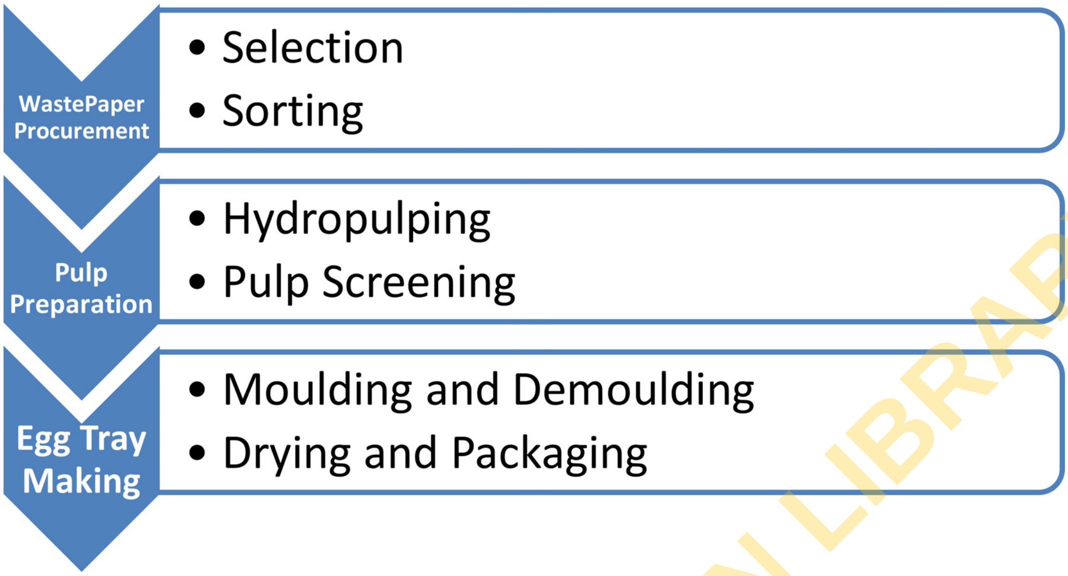

Fig. 3. Paper Egg Tray Production.

However, the pulping activities can be done using hydro-pulping method which requires a common hydro-pulper; grinding, using common electric grinder or pounding, using mortar and pestle. The choice of the University campus for production activities was a coincidence for convenience and accessibility.

And according to the flowchart, waste papers were first sorted and made into pulp at 5% consistency in a typical drum-type hydra-pulper. The hydra-pulper was of 0.025 m^3 capacity and with an upper-loading impeller. Later, the pulp was transferred into the mixing tank (120 L plastic container) to lower the consistency to about 4% further. The stock was then transferred into the pulp vat beneath the moulding unit after additives addition. Finally, the moulding unit was made to reciprocate and immersed in the prepared stock. The forming mould was machined and perforated aluminum cast covered with fabric mesh. Transfer mould was made of the same material and had a reverse resemblance to the mould. Both forming and transfer mould had vacuum chambers and hoses attached to each at the back. Forming mould was immersed in the stock, and a vacuum suction was applied through the reverse. This action steadily dragged the fibres in the slurry to the mould to form its shape. The forming mould was removed from the slurry vat while still under vacuum, which allows water to be drained from the wet paper trays. The wet trays were absorbed by the transfer mould through vacuum suction and later ejected through compressed-air-blowing (Einhell INOX 1250 Vacuum/ Hoover). Vacuum suction and compressed-air-blowing interchange were regulated by the control valve installed. The excess water from the wet tray was channelled outside the pulp vat. The wet tray was collected on a metallic sheet and sun-dried.

Results and discussion

Evaluation of paper egg tray machine

As shown in Plate 1, the paper egg tray-making machine was developed from the available materials procured in Ibadan metropolis. The machine of 35 kg weight was produced at a total cost of N76, 720 ($210), as shown in Tables 1 and 2. The machine's evaluation results showed a power rating of 1.4 Kw (Fig. 4). Also, the machine could be operated manually with a minimum of one worker while it adopts reciprocating movement for its moulding and de-moulding activities. Pulp slurry of 4% consistency was appropriate for the machine's optimum performance. Cassava gel could also be added to the pulp slurry to serve as a sizing agent following [18]. The machine had a production capacity of about ten trays per hour. Therefore, the moulding duration was about six minutes, followed by 12 h of sun-drying.

The successful development of the paper egg tray-making machine is worthwhile because local production and distribution of paper trays will be enhanced, environmental sanitation promoted and jobs created for teeming youth. Moreover, due to ergonomic concerns, the machine was made light, movable and the maximum machine height of 760 mm was maintained. Nevertheless, the developed machine has many distinct advantages over previous attempts at developing a low-cost paper egg tray-making machine.

In the work of Onilude [12], a machine designed to produce 30-cell paper egg trays was developed using the technology that involved the forming mould being lowered into the pulp vat. In the end, a paper egg tray was formed, having irregular-shaped cavities, excessive thickness and unacceptable quality assurance (Plate 2). Also, the mould used in the machine was made of a pre-perforated iron sheet of unspecified mechanical strength. Moulds for paper egg tray production must

Table 1.
Bill of Engineering Measurement and Evaluation (BEME 2019) for Paper Egg Tray Machine.

S/N	Type	Material	Description	Quantity	Cost (N)
1	**Frame**				
	Square Pipe for Base	Mild Steel	25 × 25 × 300 mm	4	1000
	Bolt and Nut	High Carbon	12 mm	4	120
	Iron Rod as Column	Mild Steel	¢15 mm, 300 mm length	4	1000
2	**Moulding and Demoulding Unit**				
	Flat Bar	Mild Steel	25 × 300 × 8 mm	4	600
	Metal Sheet for Vacuum Chambers	Mild Steel	600 × 600 × 4 mm	2	1000
	Bolt and Nuts	High Carbon	12 mm	8	480
3	**Mould Castings**				
	Aluminum Alloy	Aluminum	15 kg	1	10,500
	Charcoal		1 bag	1	2500
	Parting Powder			1	1000
	Pattern Making	Plastic	300 × 300 mm	4	5000
	Machining				6000
	Labour				2000
4	**Others**				
	Pulp Vat	Galvanized Iron	¢350 mm, 350 mm height	1	7500
	Vacuum Pump		Drum-type Hoover	1	15000
	Hose	PVC	¢12.5 mm	4 yards	1000
	Clips			6	120
	Control Valves			2	400
	Workmanship				10000
	Painting	Gloss Paint	2 coatings		3000
	Transportation				2000
	Electrodes			1.5 pckt	1500
	Metallic Tray	Steel		4	1500
	TOTAL				**N76,720**

Table 2.
Weight of Machine Components.

S/N	Components	Mass (kg)	Weight (N)
1	Forming mould	5	49
2	Transfer mould	5	49
3	Upper vacuum chamber	2	19.6
4	Lower vacuum chamber	4.5	44.1
5	Frame (column)	3	29.4
6	Pulp vat	7.2	70.56
7	Hoover	7	68.6
8	Wet paper egg tray	0.3	2.94
9	Accessories	1	9.8
	Total	**35kg**	**343N**

meet specific strength standards for adequate efficiency and durability and must be rust-resistant to maintain the aesthetic value of the trays. This awareness informed the choice of aluminum alloy and stainless metal in constructing paper egg tray moulds. Furthermore, the vacuum suction rating of the water pump used in the previous attempt was not stated; it is believed to be below the standard suction rating (500 mmHg) required for paper egg tray production. Meanwhile, this latest development corrected or improved upon all the inadequacies mentioned above of the previous paper egg tray machine's designs.

However, emphasis should be laid on the manufacture of machine moulds. The use of Computer Numeric Control (CNC) equipment should be employed in making the moulds to guarantee their perfect interlocking. Moreover, if a sand casting is adopted, "mould finishing" should be considered. Also, a suction pump of sufficient rating and appropriate category should be engaged to ease production [19–22,25].

Evaluation of paper egg trays produced by the machine

The results of the evaluation of the paper egg trays (Plate 3) manufactured using the manually operated machine, are shown in Table 3. The table shows 298 g and 86 g for wet and dry trays, respectively. Both dry and wet weights recorded were higher when compared with conventional paper egg trays used in Nigeria. The elevated weights could result from high pulp slurry consistency (4%) and long wet-tray forming duration. The dimensions of 300 × 300 mm were appropriate, for they can conveniently fit into the secondary packaging material (carton box) for the poultry eggs. The tray colour of "white", number of cells (30), cell diameter (35 mm), and cell depth (25 mm) were appropriate and in agreement with other egg trays being used in Nigeria [23,24]. The trays can accommodate varying diameters from 25 to 35 mm. Meanwhile,

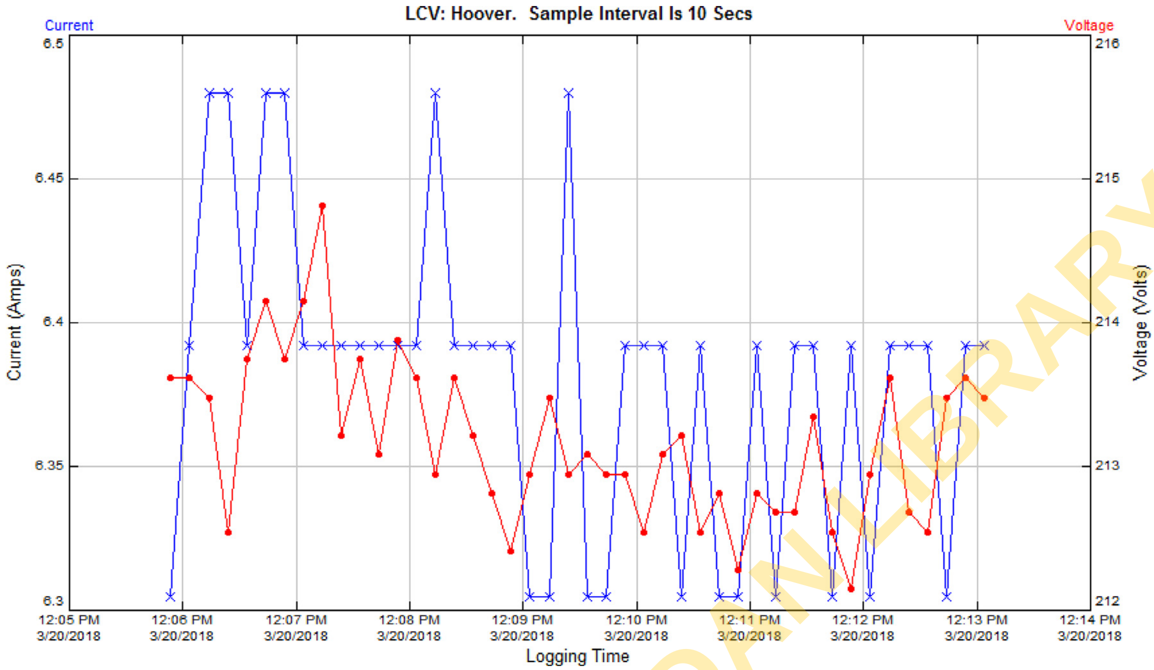

Fig. 4. Power Rating Chart of the PET-Making Machine.

Plate 1. Manually Operated Paper Egg Tray-Making Machine.

Table 3.
Results of Evaluation of Paper Egg Trays Made from Manual Machine.

S/N	Properties	Trays from Developed Machine	Existing Paper Egg Trays
1	Dimensions L * W (mm)	305 × 305	297 × 290
2	Caliper (mm)	1.35 ± 0.08	1.4 ± 0.09
3	Wet Weight (g)	298	266
4	Dry Weight (g)	86 ± 1.56	76 ± 3.16
5	Capacity (No of Eggs)	30	30
6	Cell Diameter(mm)	35	36
7	Cell Depth (mm)	25	25
8	Crest Height (mm)	10	23
9	Colour	White	White
10	Quality Assurance	Average	Acceptable

The integer before "±" connotes mean values of 5 replicates and the figure after "±" represents standard deviation

Plate 2. Paper Egg Tray made by Previous Researcher.
Source: [12].

Table 4.
Results of Vibration Resistance of Manufactured Paper Egg Trays.

Experimental PETs	Cassava Gel	PVA	HEC	Control (0%)	Existing PET
Moving Vehicle					
No of Loaded Eggs	90	90	90	90	90
No of Cracked Eggs	3	3	2	2	4
Eggs Failure (%)	3.3	3.3	2.2	2.2	4.4
Vibrating Table					
No of Loaded Eggs	90	90	90	90	90
No of Cracked Eggs	3	4	2	2	8
Eggs Failure (%)	3.3	4.4	2.2	2.2	8.8

the deficiency in the crest height of the tray could be traced to the manufacturing inadequacy of the forming mould, which had shortened crest height. This new product improves the previous attempts by researchers at locally producing paper egg trays (Plate 2). All the deficiencies of the previous designs were corrected in this new one.

Moreover, the little success recorded during the machine evaluation and tray production could be as a result of specific measures observed, which included pulp preparation of $\leq$ 4% consistency, application of the water-proof coating on the transfer mould to ease de-moulding of wet egg trays, use of mesh hole size of $\leq$ 0.6 mm, plugging of mould parting lines, and the evacuation of excess water from the wet trays.

Vibration resistance of paper egg trays

Table 4 shows the results of vibration resistance of manufactured paper egg trays. Three samples each of the existing PETs fortified with varying solids concentrations of additives, comprising 10% of Cassava Gel, 5% of Polyvinyl acetate (PVA), 0.5% of Hydroxyethyl Cellulose (HEC) and control (0% additive) were compared with the manufactured PETs. Trays loaded with eggs were subjected to vibration induced by a moving vehicle on a rough Nigerian road of about 30 km distance at 60 km/hr speed. Ditto to a vibrating table of about 5 Hz vibration frequencies, for 15 min. However, the results showing an average of 2.0% and 4.0% egg failure was recorded for the existing and manufactured egg trays, respectively, using a vibrating table and a moving vehicle. The slight variation in the vibration failure could be because the manufactured trays were not perfect during production, which, therefore, calls for improvement in subsequent trials. On the other hand, the variation in

Plate 3. Paper Egg Tray Made with Manual Paper Egg Tray Machine.

egg failure during vibration could be due to the uninterrupted stress imposed on the eggs by the vibrating table during the test compared with that of the moving vehicle.

Innovation and novelty in the paper egg tray-making machine and its product

It is pertinent to point out some of the innovations and novelty of the machine and its product (paper egg tray) and shed more light on the exciting highlights of this work. The statements as made below highlight the advances made through this work:

I This work shows that metal scraps (wastes) can be entirely used to locally develop a machine capable of producing paper egg trays. This will reduce over-dependence on foreign machines, spare parts and maintenance technicians for egg tray machines. It is also hoped to improve environmental sanitation and job creation. Also, the trays so produced from the machine were comparable with the existing ones, having been produced at unprecedented pulp consistency of 4%.

II This work demonstrates the fact that a domestic vacuum cleaner of adequate suction rating could be used in place of vacuum pump as required for paper egg tray production. Vacuum pump of adequate rating may be costly and at times scarce; the use of a vacuum cleaner (hoover) in its place is considered an exciting novelty.

III The new knowledge as shown in this work is the procedure highlighted for the machine and paper egg tray production. Special attention should be placed on pulp slurry production and its consistencies for paper egg trays production.

IV This work shows that metal and paper wastes could be converted to wealth by using them as essential raw materials as demonstrated in this study. This endeavor will encourage sustainable development in terms of revenue generation, environmental sanitation and job creation for teeming youths, as a focus of African Union Agenda 2063.

Conclusions and recommendations

The paper egg trays which are the most universally acceptable packaging materials for chicken eggs are regularly imported, costly and scarce in Nigeria. This challenge is due to hitches in obtaining and managing foreign-made machines for trays' local production. This study was therefore aimed at locally developing and evaluating the performance of a low-cost paper egg tray-making machine to ease the local production and distribution of paper egg trays in Nigeria, turn waste to wealth and create employment for teeming youths. By using metal scraps as construction materials and a sand-casting method for mould manufacture, a 30-cell manually-operated machine was locally developed, and its performance evaluated. The paper egg trays having dimensions of 300 $\times$ 300 mm, cell diameter of 35 mm, cell depth of 25 mm, and wet and dry weights of 298.0 g and 86.0 g, respectively, were produced by the machine, evaluated, and found comparable with the existing ones. In addition, the vibration resistance of the trays produced using the manually-operated machine was compared with the standard and existing paper egg trays. The results showed that egg failure for the developed and existing paper egg trays were 2.0% and 4.0%, respectively. The development of a manually-operated low-cost paper egg tray-making machine was successful and could ease the local production and distribution of paper egg trays in Nigeria. It is also hoped to engender waste-to wealth creation and youth empowerment. Therefore, it is recommended that further research work on the development and improvement of the manual paper egg tray-making machine be carried out.

Declaration of Competing Interest

The authors declare no conflict of interest.

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