Development and Performance Evaluation of a Dryer for Preserving Vegetable Leaves

Jamesmary E. AYANRU[1], Matthew S. ABOLARIN[2], Omotayo I. OGUNWEDE[3*], Henry I. MORKAH[4], Adeshola O. OPENIBO[5]

[1,2,4,5]Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria
[3*]Department of Mechanical and Mechatronics Engineering, Federal University of Transportation, Daura, Nigeria

[1]dsolution4real131@gmail.com, [2]msabolarin2006@gmail.com, [3*]tayowede@gmail.com, [4]henrymokah1@yahoo.com, [5]adeshola.openibo@gmail.com

Abstract

Vegetable leaves need to be well preserved and kept in their best quality to avoid excess wastage when they are out of season, by minimizing pathogenic bacteria that cause decaying. As a result of this search, a machine dryer was created to preserve the vegetable leaves throughout the surplus season. The drying machine has two identical rectangular cabinets with three identical tray plates. It is designed to be electrically powered by means of a circuit box that includes a temperature controller, a contactor, and a switch. A heating filament with 1,800 W capacity serves as the heat source. The developed machine also contained a 12V, 25W DC motor and a propeller shaft connected with fans that extract moisture from the drying materials, such as fluted pumpkin leaf (Telfairia occidentalis), water leaf (Talinum triangulare), and bitter leaf (Vernonia amygdalina). The result shows the mass of water removed during drying of the aforementioned three varieties of vegetable leaves was 3.500 g, 4.387 g, and 3.850 g, respectively, to attain the required moisture content for preservation. The amount of moisture extracted was 72.9%, 75%, and 73.3%. The total heat energy required to extract moisture was 2,858.4KJ, and the efficiency of the developed machine was evaluated to be 70.6%. This implies that the developed machine is capable of drying the three varieties of vegetable leaves used for this study to a required moisture content to avoid waste and reduce high prices when out of season, among other benefits.

Keywords: *Vegetable, dryer, design, fabrication, heat.*

1.0 Introduction

Vegetable refers to the edible product of a plant. They are basically plants inform of leaves which serve as vegetable nutrients when eaten (raw or cooked) (e.g. Spinach, cabbage, salad greens), while others cannot be eaten raw (e.g. broccoli and sprouts). They are rich in food nutrients like vitamins and minerals but health wise, low in calories. They serve as resistance to heart attack and high blood pressure. Vegetables are best prepared for eaten immediately after picking from the farm, to prevent changes in colour, texture, flavor, sugar content and nutrient, which will go a long way to prevent destroying enzymes that would have caused changes in content value of the vegetable leaves. In case the vegetables are not consumed immediately after picking, then there is need to preserve them to retain their quality whenever they are to be eaten. Preservation is the activity or process of retaining the quality of a product to be intact or free from damages or decay. It is the act of keeping products, especially food items in a good state either by refrigeration, fermentation or drying in order to prevent decay or damages. It is impossible to overstate the significance of preserving vegetable leaves, which involves reducing harmful germs, maintaining the highest possible quality, and preventing waste. The importance of including vegetables in our diet is already becoming more widely recognized, although vegetable leaves have received less attention than seeds [1-3]. It is one thing for the world to be aware of the need of adding vegetables to our daily diet and most importantly to be aware of suitable methods of preserving them. It is a fact that green vegetable leaves are highly perishable and thus have low durability. Accordingly, Karl et al. [4] said that "drying" should be taken into consideration as a good preservation method. The damage, deterioration, or spoiling of raw food products after prolonged usage is a significant issue in the food processing sector. Seasonal and very perishable are raw vegetables like pumpkin leaves, bitter leaves, water leaves, and other vegetable leaves including Asian greens, cabbage, kale, leek, okra, etc. One of the first techniques for preserving food in the modern world is drying. Asaad [5] developed a solar drying machine and studied its efficiency in drying of some fruits and vegetables. Drying as a means of preservation involves the application of heat in dehydrating a product. Julie (2007), claims that drying was deemed a great way for preserving crops such as garlic, sweet corn, carrots, and so on. Three popular techniques for drying leafy vegetables were outlined by [5]: sun drying, solar drying, and oven drying. Vegetable and seed preservation have been the subject of several studies; nevertheless, it was found that more research has been done on fruits and seeds preservation than on vegetable leaves [3]. Additionally, there aren't many relevant designs and fabrications on vegetable leaf dryers, but the most have been on cloth dryers. Therefore, the goal of this research is to create

a portable device for preserving vegetable leaves by drying them.

2.0 Methodology
2.1 Materials
A designed and fabricated portable machine for drying vegetable leaves have been developed, having one source of heat, a moisture extractor (consisting of a propeller and a 12V D.C motor), a transformer and a rectifier, a circuit box (consisting of an electronic temperature controller, contactor, switch), trays, cable wires among others.

The materials used for this development include:

(i)   Mild Steel Plate: This was used for the body (inner and outer) of the machine, door plate, the base/ seat of the machine, the circuit box and a propeller.

(ii)   Mild Steel Pipe: This was used for the body frame of the machine, door frame and base frame of the machine.

(iii)   Mild Steel Angle Iron: This was used for the inner tray seat and the legs of the machine.

(iv)   Stainless Steel Plate: This was used for the tray plates.

(v)   Galvanized Plate: This was used for the top of the support structure

(vi)   Mild Steel Flat Bar: This was used for the door handle and locker.

(vii) Fiber Glass: This was used for the insulation.

2.1.1 Material Selection
The materials used for this development were mainly mild steel though ranging from plate to pipe, to angle iron. The materials were sourced locally from Minna building materials open market and the construction work was done in Minna. Mild steel was more selected or used for the fabrication of this machine due to the following reasons:

(i)   Affordability and Availability: Mild steel is relatively cost effective and available compare to many other special materials.

(ii)   Malleability, Ductility and Weldability: Mild steel has high impact strength.

(iii)   Machinability: Mild steel can be easily machined, using simple machines techniques.

(iv)   Strength and Durability: Mild steel has a good strength-to-weight ratio and ishighly durable.

2.1.2 Design Consideration
The following are the factors that were put into consideration in designing, fabricating and developing the portable vegetable leaf drying machine:

(i)   The size/ dimensions and weight of the vegetable leaf drying machine with respect to portability.

(ii)   The light texture of the vegetable leaves.

(iii)   The number of compartments of the cabinets to accommodate sufficient quantity drying capacity per volume. And in urgent situations, to accommodate two different variety of the tested vegetable leaves.

2.1.3 Design Theories
The developed machine consists of two cabinets: each having three trays (drying plates) to accommodate reasonable quantity of vegetable leaves. The cabinets serve as the housing of the developed machine where the vegetable leaves will be placed during the drying process. The area and volume of the cabinet are given in equation 1 and 2 respectively and the parameters governing them were determined using a Vernier calliper.

$$AC = l \times w \qquad\qquad\qquad\qquad (1)$$

$$VC = l \times w \times h \qquad\qquad\qquad\qquad (2)$$

where:

$A = Area\ of\ the\ cabinet\ (m^2)$

$V = Volume\ of\ the\ cabinet\ (m^3)$

$l = length\ of\ the\ cabinet\ (m)$

$w = width\ of\ the\ cabinet\ (m)$

$h = height\ of\ the\ cabinet\ (m)$

(a) Determination of Area and Volume of Trays
The six (6) trays were of equal dimensions:

$$l = w = 30.4cm = 0.304m$$
$$h = 1.9cm = 0.019m$$

where:
$l = length \ of \ the \ tray$
$w = width \ of \ the \ tray$
$h = height \ of \ the \ tray$

Hence, the area of each tray was determined from the equation (1)

$$Area \ = \ l^2$$

(b) Frame Design
The frame of the vegetable leaf drying machine provides structural support and stability to the entire machine. The material used for the frame was of high resistance to withstand the smoke/ vapour during drying. The choice of dimensions of the frame are as follows:

$$lf = 83cm = 0.83m$$
$$bf = 37cm = 0.37hf$$
$$hf = 90cm = 0.9m$$

(c) Determination of the Speed of Rotation of the Propeller Shaft
The speed of rotation of the shaft can be determined by the equation

$$Shaft \ Speed \ (m/s) = \frac{Shaft \ diameter \ (mm)}{19108} \times r.p.m \tag{3}$$

Where the diameter of the shaft used is 6 mm and the rotational speed of the shaft in $r.p.m$ is 2,500.

(d) Determination of Rate of Temperature Change
This refers to the ratio of the difference in temperature over a period of time, measured in $0_C/s$ When the switch in the circuit box and the power switch are both on, the shaft rotates for few seconds and then the initial (room) temperature is displayed by the temperature controller. The rate of temperature change for each material was determined using various temperature differences and their respective time. The maximum drying temperature set on the temperature controller is 75^0C. It took about 20 to 30 seconds to attain this temperature, as the time taken depends on the nature of the material to be dried with respect to the initial moisture content.

(e) Determination of Expected Quantity of Moisture to be Removed
The quantity/ amount of moisture (A_m) to be removed was necessary in order to ascertain the quantity/ amount of water needed to vaporize and evaporate from the total mass of drying material to be tested for. Here, the three varieties of vegetable leaves were used, one after the order. In each case, this was calculated, using equation 4.

$$A_m = \frac{m_1 - m_2}{m_1} \times 100 \tag{4}$$

where:
(m_0) =The mass of the pan used in weighing the vegetable leaves $= (g)$
$m_1 = $ True mass before drying (g)
$m_2 = $ True mass after drying (g)
$m_b = $ Scale reading before drying (g)
$m_a = $ Scale reading after drying (g)
$m_m = $ Mass of the moisture removed (g)

(f) Heat Energy Required to Remove Moisture (Om)

This refers to the quantity of heat (in Joules) required or needed to raise the temperature of the drying materials to a desired/ programmed level sufficient for drying and then evaporate the moisture. This can be determined by the sequential steps below:

Firstly, heat needed to raise the temperature of the wet vegetable leaves to a reasonable temperature in order to remove the moisture. The equation 5 (Mercer, 2007) was applied as shown below:

$$Q = mcp\Delta\theta \tag{5}$$

where:

$Q = Quantity\ of\ heat\ needed\ to\ remove\ the\ moisture\ (J)$
$m = The\ mass\ of\ the\ drying\ material\ (kg)$
$cp = specific\ heat\ capacity\ of\ the\ drying\ material\ (Jkg^{-1}K^{-1})$
$\Delta\theta = Change/\ Difference\ in\ temperature\ (^{0}C)$

Secondly, heat required to evaporate the moisture from the drying materials. This is determined by the equation 6 (Mercer, 2007)

$$Q = mL \tag{6}$$
$$Q = mm \times L$$

Where:

$Q = Quantity\ of\ heat\ required\ to\ evaporate\ the\ moisture\ (J)$
   m_m= Mass of moisture removed (kg)

$L = Specific\ latent\ heat\ of\ vapourization\ (J/kg)$
But
$$L = hg - hf \tag{7}$$
Where:
$hg = Enthalpy\ for\ final\ temperature\ (J/kg)$
$hf = Enthalpy\ for\ ambient\ temperature\ (J/kg)$

(g) Components of the developed machine and their respective functions

1. Moisture Extractor: This sucks out the moisture after an appropriate temperature suitable for drying is reached. It is thus, controlled by the temperature controller which makes it to act as an extractor and as well as a regulator. The moisture extractor was fabricated to work with a 12V, 25W D.C motor and a propeller. It is also designed to have an exhaust.

2. D.C Motor: the capacity of the D.C motor used was 12V, 25W. The primary function is to convert the A.C coming from the cable wire through the temperature controller to D.C.

Plate 1: The Moisture Extractor   Plate 2: The D.C Motor

3. Propeller Shaft: A propeller shaft was constructed which rotates immediately the cable wire has been plugged and switched on. It stops rotating once a room temperature is attained as displayed by the temperature controller.

4. Heating Filament: This is a hardened like wire which serves as a heating source with its two (2) terminals connected to the two ends of the machine, between the top of the supporting structure and the base of the machine itself inform of a U- shape. The capacity of the heating filament used was 1,800W.

Plate 3: The Propeller fan   Plate 4: The Heating Filament

5. Drying Trays: Six (6) trays were used for the development of the machine and each were of equal dimension thus, equal area and equal volume.

Plate 5: The Drying Tray

6. Cable Wire and Plug: A copper cable wire of length 100cm and 2.5mm thickness and a 15A plug was used. This was connected to the heating filament through a small connector.
7. Contractor: A contractor is an electrical controlled switch used for switching an electrical power circuit. This is the electrical device that will hold the flow of current from the cable wire through the temperature controller from getting to the extractor when the temperature has not yet reached the programmed value (i.e. when the extractor has not started working) and also supply/ allow the flow of current to power the extractor when the set temperature value has been reached.
8. Temperature Controller: The temperature controller being an electromechanical device works like a thermostat such that once the temperature set is reached or attained the heating source stop working and the moisture extractor sucks out moisture thus, acting as a regulator at this time. Once the temperature drops as indicated on the temperature controller, the heating source picks-up again and once the set temperature (on the temperature controller) is reached again, the heating source stops working and the moisture extractor sucksout the moisture and it continues just like that, ensuring the temperature doesn't exceed what was programmed for being the primary function of the temperature controller. The temperature controller has a relay which allows the propeller shaft to rotate shortly before a room temperature is displayed on the temperature controller.

Plate 6: The Contactor   Plate 7: The Temperature Controller

9. Circuit Box: This is a box-like object constructed (using mild steel plate) to house the temperature controller, the switch and the contactor.
10. Fibre Glass: This was used to serve as an insulator so as to reduce heat loss to the surroundings thereby ensuring high efficiency.

11. Ceramic Insulator: This serves as an insulator to the cable.
12. Transformer: A transformer is an electromechanical device that steps up or steps down voltages. In this case, it is a step-down transformer. This in the sense that it was installed to work with the D.C motor and because the normal voltage from the PHCN (being 220V) is too high and might burn the motor, there is need for a step down being the primary function of the transformer. It also helps to convert the AC to DC should there is no normal power supply from PHCN. The transformer used as shown in Plate 8 consists of a neutral wire and three (3) other optional wires rated 185V, 220V and 255V thus, that of the 220V was used (connected to the neutral). This implies the input voltage V_p of the transformer used was 220V while the output voltage V_s was 12V.
13. Rectifier: The rectifier is another electrical device that was used in this development. The primary function of the rectifier is to convert the outputvoltage of 12V by the transformer from A.C to D.C.
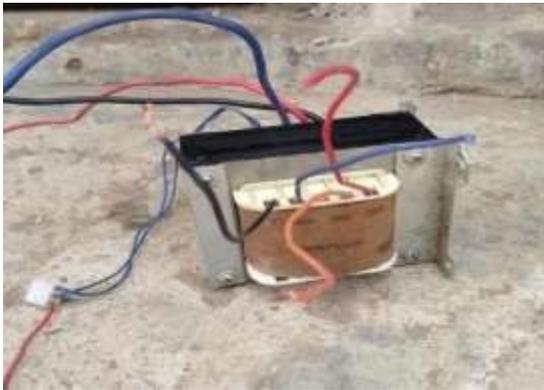

Plate 8: The Transformer   Plate 9: The Rectifier

(h) Principle of Operation of the Machine
The portable machine was constructed with the idea of working electrically, using a heating filament as a source of heat energy thereby converting electrical energy to heat energy. The working process is such that the temperature controller is manually set to anappropriate drying temperature of about $75^0C - 100^0C$ depending on the drying material. Once the cable wire is plugged to a $220V$ source and switched on and then the switch in the circuit box also on, the propeller rotates immediately and stops immediately a room temperature of $36^0C - 37^0C$ is displayed on the temperature controller. From this temperature, electrical energy (in form of current) which is already in the temperature controller but held by the contactor then flows to the heating filament thereby converting the electrical energy to heat/ thermal energy. The magnitude of thermal energy continues to increase until $\pm2^0C$ of the programmed temperature is reached. At this moment, the temperature stops increasing and the moisture extractor begins to play its role like the name implies (i.e extracting the moisture), as the shaft begins to rotate again and at the same time, regulating the system. After a little while,the temperature begins to rise again gradually, as indicated by the temperature controllerand the moisture extractor pauses. And so it continues until an appropriate drying temperature is reached when the propeller shaft continues to rotate for a longer time.

(i) Fabrication and Assembly
Various parts of the developed machine were fabricated using appropriate fabrication techniques and procedures beginning from appropriate selection of materials to important design considerations, cutting and shaping, welding and joining, machining and finishing, installations, final assembling and spraying; all as explained below:
(1) Cutting, Shaping and Drilling: The materials selected (mild steel, stainless steel and galvanized steel) were cut into various based on the design specification, using appropriate tools and holes were drilled in appropriate positions, using the hand drill.
(2) Welding and Joining: The cut, shaped and drilled materials were welded using appropriate welding techniques and putting proper alignment into consideration.
(3) Connections and Installations: The electrical equipment like the electric motor, temperature controller, switch, contactor, transformer and rectifier amongothers were properly connected considering the positive, negative and neutral wires (as the case may be) and installed appropriately.
(4) Machining and Finishing: The cut, shaped, drilled, welded and joined components were properly machined and thus, given a good finishing which include but not limited to spraying.
(5) Final Assembly: All components were assembled together.

Plate 10: The Fabricated Vegetable Leaf Drying Machine.

3.0 Results and Discussion
3.1 Results
Below is the outcome of the experiment carried out with the designed dryer.

(a) Area and Volume of Cabinets
The area and volume of the cabinets of the developed machine were determined from (1) and (2) above respectively as shown below:
$$AC = 0.375m \times 0.3m$$
Area of each cabinet = $0.1125m^2$
But the developed machine consisted of two cabinets of equal dimensions. Hence, total area of the cabinets of the machine = $0.1125 \times 2 = 0.225m^2$
On the other hand, volume of the cabinet $Vc = l \times b \times h$
$$Vc = Ac \times h \, 0.1125 \times 0.35$$
$$Vc = 0.0394m^3$$
But total volume of the drying machine = drying capacity = $2 \times Vc \, 2 \times 0.0394$
$0.0788m^3$

(b) Area and Volume of Trays
The area and volume of each tray was determined from the equation (1) and (2) respectively as shown below:
$$Area \; of \; each \; tray = 0.304^2 = 0.0924m^2$$
But the developed machine consists of 6 trays of equal dimensions.
Total area of trays in the machine = $0.0924 \times 6 = 0.55m^2$

On the other hand,
$$Volume = 0.0924 \times 0.019$$
$$Volume \; of \; each \; tray = 0.001756m^3$$
But total volume of the tray = $0.001756 \times 6 = 0.01m^3$

(c)   Area and Volume of the Frame
The area and volume of the frame were determined from (1) and (2)
$$Af = l \times b \; 0.83 \times 0.37$$
$0.31m^2$

$$Volume \; of \; the \; frame \; Vf = l \times b \times h$$
$$Vf = 0.83 \times 0.37 \times 0.9$$
$$= 0.28m^3$$

(d)   Speed of Rotation of the Shaft (m/s)
The speed of rotation of the shaft was determined by (2.9) in chapter three above as shown below:

$$Shaft\ Speed\ (m/s) = \frac{6}{19108} \times 2,500$$
$$Shaft\ Speed\ (m/s) = 0.785m/s$$

The shaft rotated for 4s before the initial temperature of 31^0 C and 45^0C for the pumpkin leaf and the water leaf respectively, as displayed by the temperature controller.

(e) Rate of Temperature Change

The average rate of temperature change of the fluted pumpkin leaf and water leaf were determined using an experiment involving change in temperature over time. The results are 0.022 ^{O}C and 0.016 ^{O}C respectively. The readings of the experiments and results are as shown below:

Table 1: Fluted pumpkin leaf (at initial temperature 31^OC)

S/N	Temperature Readings (^0C)	$\Delta\theta(^0C)$	Time (s)	$\frac{\Delta\theta}{t}$ ($^0C/s$)
1.	31	0	0	0
2.	38	7	300	0.023
3.	41	3	60	0.05
4.	51	10	315	0.032
5.	61	10	615	0.016
6.	71	10	735	0.014
7.	75	4	225	0.018

Since change in temperature is certainly not constant, the average rate of temperature change was determined.

Average rate of *temperature change* $= 0.022^O C$

Table 2: Water leaf (at initial temperature of $45^O C$)

S/N	Temperature Readings (^0C)	$\Delta\theta(^0C)$	Time (s)	$\frac{\Delta\theta}{t}$ ($^0C/s$)
1.	45	0	0	0
2.	50	5	90	0.056
3.	55	5	200	0.025
4.	60	5	330	0.015
5.	65	5	600	0.008
6.	70	5	920	0.005
7.	75	5	1,500	0.003

Average rate of *temperature change* $= 0.016^O C$

(f) Expected Quantity/ Amount of Moisture to be Removed

The developed machine was used to conduct a test in order to determine the amount of moisture removed from each variety of vegetable leaves. The result is recorded as represented in the table below:

Table 3: Experimental analysis of moisture content removed

Vegetable Leaves	m_b (g)	$m_1(g)$ $m_a - m_0$	$m_{a(g)}$ $m_a - m_0$	$m_2(g)$ $m_1 - m_2$	$m_w(g)$
Pumpkin leaf	5,100	4,800	1,600	1,300	3,500
Bitter Leaf	5, 550	5, 250	1,650	1, 400	3,850
Water Leaf	6,150	5,850	1,762.5	1,462.5	4,387.5

where m_0 = 300g or 0.3kg
Now applying equation (4) above:
A_m (*Pumpkin Lea*f) = $\dfrac{3,500}{4800m} \times 100$

$= 72.9\%$

A_m (W*ater Lea*f) = $\dfrac{4,387.5}{5,850} \times 100$

$= 75.0\%$

A_m (*Bitter Lea*f) = $\dfrac{3,850}{5,250} \times 100$
$= 73.3\%$

The representation below is a graph of the mass of moisture versus the mass beforedrying.

(g) Effect of Drying with Respect to Removal of Mass

The initial moisture content of the three (3) varieties of drying materials was checked byplacing them one after the other on a weighing scale. The drying materials are then heated for a reasonable period of time until it gets dry. The samples are then re-weighed.The difference between these two weights gives the mass of water removed.

Moisture is extracted from the vegetable leaves by the moisture extractor of the developed machine. The amount of moisture extracted was determined for the three selected varieties of vegetable leaves and the result is presented in Table 1

(h) Effect of Drying with Respect to Quantity/ Amount of Moisture Extracted by Machine

Table 4 Amount of moisture (%) removed from each leaf

Vegetable Leaf	Initial mass (g)	Mass of water removed	Amount of moisture removed (%)
Fluted Pumpkin Leaf	5,100	3,500	72.9
Water Leaf	6,150	4,387.5	75
Bitter leaf	5,550	3,860	73.3

The result in table 4 above shows that the water leaf had the highest mass of water removed through the process of drying and thus, the highest amount of moisture removed by the extractor of the developed machine.

(i) Effect of Heat Energy in Drying up the Leaf
A sufficient quantity of heat was needed to be generated by the machine through the heating filament to enable adequate drying. The total heat energy (kJ) needed to extract the moisture (involving two phases) was determined using the pumpkin leaf.
Fluted Pumpkin Leaf
m_1 = 4.8kg
The specific heat capacity of fresh leaves varies from$1,255 Jkg^{-1}K^{-1} - 5,174 Jkg^{-1}K^{-1}$ (Jayalakshmy et al., 2010).
The maximum value was used.
$cp = 5,174 JJkg^{-1}K^{-1}$
$\Delta P = 75^0 C - 31^0 C$
$\Delta P = 44^0 C$
Now applying the values into equation (5)

$4.8 \times 5,174 J \times 44$

$Q_1 = 1,092,748.8J$ or 1,092.7kJ

The values of h_g and h_f at the drying temperature are obtained from psychometric chart. As such, the enthalpy value for the final drying temperature say $75^0 C$ and that of the ambient temperature $31^0 C$ are read and recorded as 402.68/kg and 50.83 kJ/kg respectively.
Now applying the values into equation (6) and (7)

$Q = m_W \times (h_g - h_f)$

$Q = 3.5 \times (562.32 - 57.83)$

Q = 1,765.7kJ

But total quantity of heat QT needed to remove water/ moisture from the drying materials (pumpkin leaf)

$Q_1 + Q_2$

1,092.7 + 1,765.7 = 2,858.4kJ

Hence, total heat needed to remove moisture = 2,858.4kJ

The results obtained are presented in Table 5

Table 5: Heat energy required to dry up the pumpkin leaf

Heat Energy Needed to dry the Leaf (J)	Heat Energy Needed to Vaporize the Moisture (J) Needed to Extract Moisture	Total Heat Energy
1,097.2	1,765.7	2,858.4

(j)   Efficiency of the developed machine

Where: Using: Efficiency $= \dfrac{\text{Work output} \times 100\%}{\text{Work input}}$

$Work\ output = Heat\ energy\ required\ to\ remove\ the\ moisture\ content$

$= mc_p\Delta\theta + mL = 2{,}858.4kJ$

$work\ input = Workdone\ by\ the\ heating\ element = IVt = Pt = 1{,}800 \times 2{,}250 = 4{,}050J$

Thus, applying:

$\dfrac{2{,}858.4}{4{,}050} \times 100 = 70.6\%$

3.2 Discussion of Result

Drying of staple foods is essential for food security and sustainability. Electric drying techniques can be considered as one of the most important methods of sustaining food demand in growing population. In this research, an electric dryer was designed, fabricated and tested. The result showed that the three leaf types employed in this investigation showed a considerable reduction in mass, according to the results shown in Table 1. However, depending on the amount of water that is contained in each substance, this disparity changes. The moisture content steadily decreases throughout the drying process. This drying behaviour is consistent with findings from previous study on plantain and potato, okra, pepper and groundnut [6-7]. Additionally, each leaf had a different moisture level; the water leaf had the greatest moisture content, at 75%. The fact that each fresh vegetable leaf still has some water or moisture content after purchase is obviously significant. Table 2 shows that the heat/thermal energy required to remove the moisture was divided into two phases: drying the leaf and evaporating the moisture content. This calls for a significant amount of thermal energy overall. The dryer functioned quick due to its significant higher heat generation. The vegetable dryer was designed using stainless steel shelves to improve efficiency and effectiveness and reduce cost within the context of low- and middle-income countries.

4.0 Conclusion and Recommendations
4.1 Conclusion

The following conclusions were made based on the result of the research.

(i)   This study designed and evaluated the performance of a vegetable leaf drying machine using stainless steel plate, mild steel plate, mild steel angle and many others. The machine can be easily assessed and maintained by vegetable farmers.

(ii)   Based on the design and performance assessment, the vegetable leaf preservation dryer has performed well in terms of efficiency at 71% and product quality. The findings underscore the potential of this inexpensive drying technology to greatly improve agricultural practices and food preservation methods as compared to current domestic technology.

(iii) The use of locally sourced materials meets engineering standards, facilitating technology transfer and adoption in resource limited settings. The dryer supports economic growth, environmental sustainability, and improved livelihoods for smallholder farmers, contributing to the comprehensive development of rural communities.

4.2 Recommendations

The following are recommended for researchers for further studies:

(i) To investigate and develop further strategies in designing and fabricating multipurpose drying machines.
(ii) To design and develop a similar drying machine that can also be powered by solar energy.

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Appendix

Appendix A: Bill of Engineering Measurement and Evaluation (BEME)

| S/N	Material	Quantity	Cost per Unit (#)	Amount (N)
1	Mild Steel Plate	$\frac{1}{2}$ Sheet	46,000	23,000
2	Mild Steel Pipe	2 Lengths	8,500	17,000
3	Mild Steel Angle Iron	$1\frac{1}{2}$ Lengths	9,900	14,850
4	Stainless Steel Plate	Quarter Sheet	88,000	22,000
5	Galvanized Plate	Quarter Sheet	36,000	9,000
6	Mild Steel Flat Bar	Quarter Length	3,600	9,000
7	Fibre Glass	$2kg$	5,000	10,000
8	D.C Motor	1 (12V)	13,000	3,500
9	Heating Element	1 Filament	3,500	3,500
10	Cable Wire	1 Yards	500	1,500
11	Plug	1	700	700
12	Contactor	1	5,500	5,500
13	Temperature Controller	1	48,000	48,000
14	Switch	1	1,500	1,500
15	Ceramic Insulator	1	500	500
16	Transformer	1	14,000	14,000
17	Rectifier	1	2,500	2,500
18	Labour/Workmanship			30,000
	Total Cost			216,050

Appendix B: 3D Model of Vegetable Leaf Drying Machine
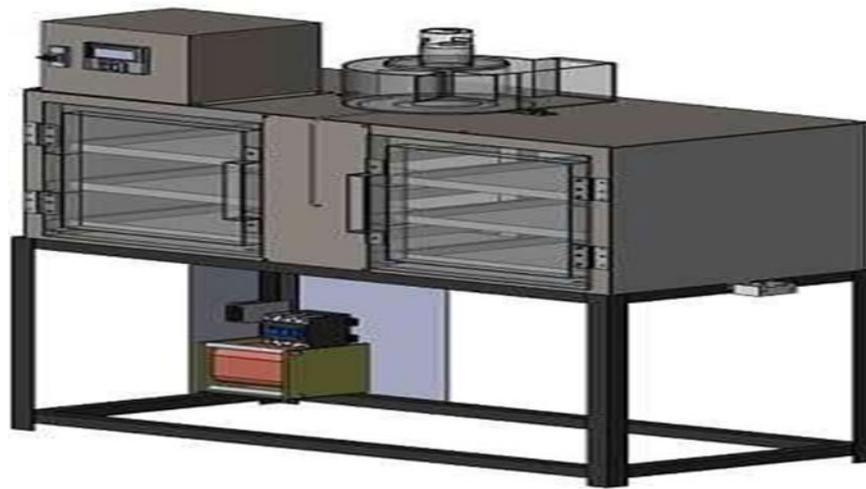
Plate 11: 3D model of vegetable leaf drying machine