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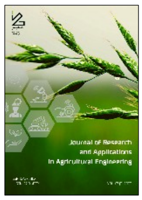

Development and performance evaluation of a hybrid solar dryer using pumpkin fruit. Part 1. Material and Methods

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The first part of our research describes the methodology for the development of a hybrid dryer and presents the methods of the study along with the general results obtained. The study presents the design, development, and performance evaluation of a hybrid solar dryer for dehydrating pumpkin (*Cucurbita moschata*) slices. The dryer integrates solar energy with a DC-powered electrical heating coil to ensure uninterrupted drying and stable thermal conditions during periods of low solar radiation. The system comprises a lagged mild-steel drying chamber, five stainless-steel trays, a centrifugal blower, temperature and humidity control sensors, and a solar-battery power arrangement. Engineering design analyses were conducted to determine heat energy requirements, moisture removal needs, airflow capacity, blower sizing, and solar energy specifications. Performance evaluation was carried out on pumpkin slices of 3 mm, 5 mm, and 7 mm thickness, assessing drying rate, moisture reduction, drying efficiency, shrinkage, rehydration behaviour, colour quality, microbial load, and proximate composition. The hybrid dryer demonstrated efficient heat utilization, improved drying uniformity, and enhanced product quality compared with traditional sun-drying. The results indicate that the developed system offers a reliable and energy-efficient solution for reducing post-harvest losses and improving value addition in pumpkin processing.

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1. Introduction

Drying is widely recognized as one of the most effective preservation methods for fruits and vegetables, as it reduces moisture content to levels that inhibit microbial activity, enzymatic reactions, and chemical deterioration [1]. Conventional open-sun drying, although commonly practiced in many developing regions, suffers from several limitations, including contamination, weather variability, prolonged drying time, and poor-quality end products [2]. These challenges underscore the need for improved drying technologies that provide controlled,

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hygienic, and energy-efficient conditions, especially for perishable crops such as pumpkin.

Pumpkin (*Cucurbita moschata*) is nutritionally valuable due to its richness in carotenoids, dietary fibre, vitamins, and minerals [3]. However, its high moisture content accelerates microbial spoilage and post-harvest losses. Developing efficient drying systems is therefore crucial for extending shelf life, enhancing product stability, and supporting value-added processing in local food chains [4].

Hybrid drying systems have gained prominence because they combine the environmental and economic benefits of solar energy with the reliability of auxiliary heating sources, eliminating downtime during cloudy or nighttime conditions [5]. Such systems improve heat distribution, stabilize drying temperatures, and reduce total drying time while maintaining product quality.

In response to these needs, this study developed a hybrid solar dryer using locally sourced materials selected for durability, thermal conductivity, availability, and cost-effectiveness. The system incorporates a lagged mild-steel drying chamber, stainless-steel trays, a DC electrical heating coil, a centrifugal blower, and a solar-battery power system for stable thermal regulation. Detailed engineering design calculations were conducted to determine moisture removal requirements, heat energy demands, airflow characteristics, blower capacity, and solar energy needs.

The performance of the hybrid dryer was evaluated using pumpkin slices of 3 mm, 5 mm, and 7 mm thicknesses. Key parameters assessed included drying rate, moisture reduction, energy efficiency, shrinkage, rehydration ratio, colour quality, microbial load, and proximate composition. The findings provide scientific evidence supporting the applicability of hybrid drying technologies for small- and medium-scale agricultural processing, with potential to significantly reduce post-harvest losses and improve food quality.

2. Methodology and design

Dryer Components

The following factors were taken into consideration while choosing the materials: cost, availability, malleability, durability, thermal conductivity, and resistance to heat and corrosion. The details of the dryer components are presented in Table 1.

Table 1. Components of the hybrid dryer

Materials/Items	Specifications
Lagging material	Fiberglass
Energy source	DC electrical heating coil (1.2 kW)
Solar battery	12-volt 200 Ah
Solar Panel (PU)	500 W (3)
Charge controller	60 A
Inverter	1500 W
Impeller (Centrifugal fan)	0.5 hp
Heating resistance wire	3 mm
Temperature and Relative humidity (sensor & control)	−30 °C–70 °C, 10%–75% RH
Control box	

Description of the hybrid dryer

The hybrid cabinet dryer's plan, elevation, and isometric views are shown in Figure 1. The frame of the drying chamber was constructed with a square pipe (0.05 m x 0.05 m) and covered with a mild steel sheet (0.12 cm thick) as shown in Figure 1. It measured 0.96 m × 0.96 m × 0.96 m in length, width, and height, respectively, giving a volume of 0.885 m^3 and a cross-sectional area of 0.71 m^2. The inner part of the dryer chamber was lagged with fiberglass to reduce heat loss during drying. Two doors were located at the front of the dryer for easy loading and unloading of trays. Each door has a length and width of 0.96 m and 0.48 m with a surface area of 0.446 m^2. To facilitate the removal of humid air, the top of the hybrid cabinet was shaped like a frustum and a chimney, and an air outlet is attached at the top, as seen in Figure 1. The dryer stand was constructed with square pipe metal (0.05 m x 0.05 m), 0.56 m above the ground, and tyres were attached to the stand for easy movement. Stainless steel was used to construct the wire mesh tray frames; this is to make them strong enough to support the weight of the samples and also ensure that the drying products are well aerated. Each tray was 0.89 m long, 0.89 m wide, and 0.05 m high, with a volume of 0.0396 m^3, and thus making the total volume of 0.1980 m^3 for the five trays. The uniform-clearance of 0.1m was allowed between trays to prevent condensation and improve the vaporization process on the drying product.

A DC electrical heating coil (1.2 kWh) attached to a constructed metal mesh (to increase heat generation) was used as a heat source. The DC electrical heating coil was powered by a 12-volt 200 Ah battery, which is charged by three 500 W solar panels. An air inlet (0.49 m x 0.50 m) through which air enters the dryer was located at the rear end of the dryer. A Temperature and Relative humidity sensor (probe), which is thermostatically operated, was also incorporated in the drying chamber. The blower, a 60 W DC centrifugal fan, blows air from the air inlet across the heating coil and supplies hot air into the drying chamber. The air velocity can be controlled on the control panel with a regulator ranging from 0.5 to 6.0 m/s.

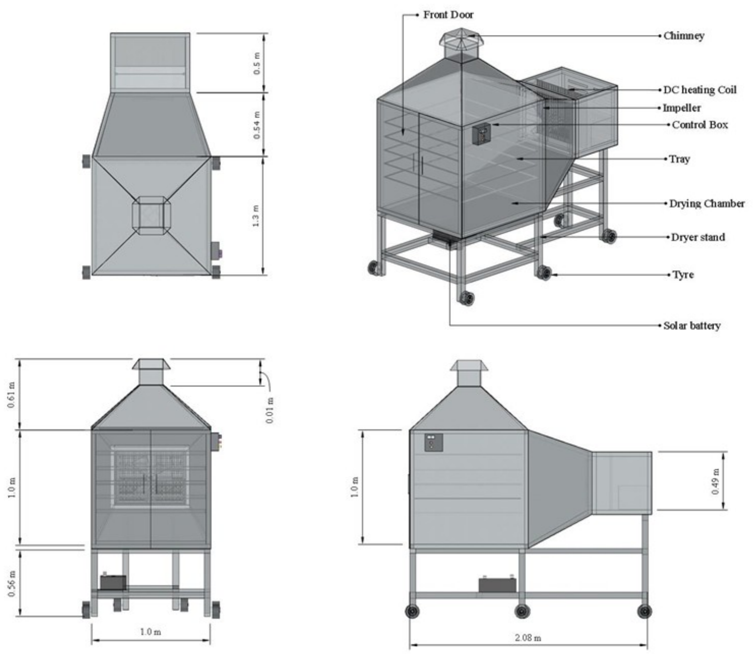

Fig. 1. Orthographic and isometric view of hybrid cabinet dryer

Design of drying chamber

The drying chamber was made of mild steel to keep the trays. The dimensions of the drying chamber were calculated based on the arrangement of the trays. The drying chamber features five trays with a 100 mm clearance between them for smooth handling.

The size of the chamber was determined as follows:

Capacity of the dryer (Q_d) = 15 kg
Bulk density of fresh pumpkin = 422 kg/m^3 (determined)
Optimum drying air velocity (2 m/s) and temperature (65 °C) [6].
Bed thickness for thin layer drying = 0.05 m [7]

Volume required $= \frac{Capacity\ of\ the\ dryer}{Bulk\ density\ of\ fresh\ pumpkin}\ (kg/m^3)$

Cross-sectional area $= \frac{Volume\ required}{Bed\ thickness}\ (m^2)$

Amount of moisture to be removed from the pumpkin slices

Equation 1, as explained by Sahay and Singh [8], was used to determine the quantity of moisture (Mw) that needed to be extracted from the fresh pumpkin slices:

$$M_w = \frac{Q_d(MC_i - MC_f)}{100 - MC_f} \tag{1}$$

where
Mw = weight of moisture to be removed (kg)
Q_d = weight of pumpkin slices to be dried per set (kg)
MC_i = initial moisture content of pumpkin (%)
MC_f = final moisture content of pumpkin slices (%)

Heat energy required in evaporating the available moisture

The amount of heat energy needed to dry the material was determined using equation 2 [9]:

$$Q = MC_{pw}\Delta T + M_w\lambda \tag{2}$$

Where
M_w = amount of moisture to be evaporated (kg)
M = weight of material to be dried (kg)
C_{pw} = specific heat of pumpkin (kJ/kg°C)
λ = latent heat of vaporization (kJ/kg)
T_2 = drying temperature
T_1 = ambient temperature

$$Power = \frac{Quantity\ of\ heat}{Time} \tag{3}$$

An electric DC heating coil of about 1.2 kW was selected to have enough capacity to effect drying in an appropriate time.

Amount of air needed for drying the sliced pumpkin

According to Ajisegiri *et al.* [10], equation 4 was used to calculate the amount of air needed:

$$Q_a = \frac{M_w}{H_{r2} - H_{r1}} \tag{4}$$

where
Q_a = quantity of air needed for drying kg/s
H_{r1} = initial humidity ratios (kg/kg dry air)
H_{r2} = final humidity ratios (kg/kg dry air)
H_{r1} and H_{r2} are obtained from the psychometric chart.

Determination of the volume of air to effect drying

The volume of air to affect drying was determined as presented in equation 5 [10]:

$$\text{Mv} = Q_a V_s \tag{5}$$

where
Mv = volumetric flow rate of drying air in (m^3/s)
Q_a = mass of drying air (kg/s)
V_s = specific volume of dry air (m^3/kg).

Determination of Blower Capacity

Blower capacity is the ability of the blower/fan to deliver the required air. The characteristic of the centrifugal fan performance curve indicated in equation 6 [11] was used as the basis for the selection.

According to [11], the Blower Capacity (BC) was computed from equation 6:

$$BC = Q_a + Q_n(n) \tag{6}$$

$$Q_n = r_a \text{ x } q_2 \tag{7}$$

Where
Q_a = quantity of heat to effect drying (kg/s)
r_a = density of air (kg/m^3)
Mv = volumetric flow rate (m^3/s)

n = is the percentage safety factor, often between 10 and 20 per cent, that guarantees a sufficient supply of air under all operating situations [11].

Design of the Solar Panels with Storage Battery

A solar system must produce enough energy to offset both its energy consumption and that of the loads. The solar panel's size and arrangement were then made to balance the system's energy production and consumption. The following design procedures were used to estimate the panel and battery sizes.

Determination of the Total Energy Consumption

One battery (12 V, 200 Ah), 1.2 kW power consumption, and 4 hours charging time were used to determine the total energy consumption:

Battery energy in watt-hours (Wh):
Energy = Voltage (V) x Amp-hour (Ah)
An 80% Depth of Discharge (DoD) was considered
Usable energy = Energy (kWh) x DoD

Solar and charge controller systems are 100% efficient, using the overall charging efficiency of 80% (0.8).

Thus, the required input energy = $\frac{\text{Usable Energy}}{\text{DoD}}$

To produce the required energy input in 4 hours,

$$\text{Panel Power (W)} = \frac{Required\ Energy\ Input}{4}$$

Using a standard 250 W panel,

$$\text{The number of panels needed} = \frac{\text{Panel Power}}{250}$$

Exergy analysis

The hybrid dryer's capacity to generate the optimal work output is known as its exergy. It is a useful technique for increasing efficiency by decreasing the system's inefficiency. The drying chamber's exergy efficiency is measured by calculating its exergy inlet, outflow, and loss. The drying chamber's entrance temperature, the ambient temperature, and the mass flow rate of hot air all affect the exergy inflow. Exergy outflow is further influenced by the drying chamber's output temperature, the surrounding air temperature, and the hot air mass flow rate. Exergy at the inlet and outlet of the drying chamber, energy loss, and exergy efficiency are calculated using equations (8 – 11) [12,13]:

exergy inflow of the drying chamber:

$$EX_{in} = \dot{m}C_p\left[(T_i - T_a) - T_a \ln\left(\frac{T_i}{T_a}\right)\right] \tag{8}$$

exergy outflow of drying chamber:

$$EX_{out} = \dot{m}C_p\left[(T_o - T_a) - T_a \ln\left(\frac{T_i}{T_a}\right)\right] \tag{9}$$

exergy loss:

$$EX_{loss} = EX_{in} - EX_{out} \tag{10}$$

$$EX_{efficiency} = \frac{EX_{in} - EX_{loss}}{EX_{in}} \tag{11}$$

Where
T_i and T_o are the temperatures of the inlet and outlet of the drying chamber in K,
T_a *is the ambient temperature* (K),
$\dot{m}$ is the mass flow rate of hot air,
and C_p is the specific heat capacity (kJ/kg °C)

The control box

The control unit is a device that regulates the system and keeps the drying chamber's temperature steady. It contains the following: a transformer (converts AC to DC), a relay (2), a temperature controller, a temperature and relative humidity sensor, a fan controller, and a temperature and relative humidity indicator, as can be seen in Figure 2.

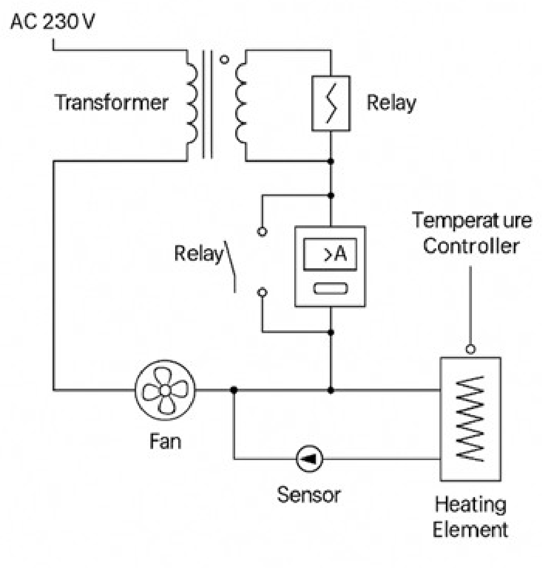

Fig. 2. Circuit diagram of the control panel

3. Performance Evaluation of the Hybrid Dryer

Sample Preparation

The pumpkin fruit variety (*Bahausheya*) was acquired from Yankaba market, Hadeja Road, Kano state, Nigeria. The samples selected were fully matured ones with uniform size and shape. They were all free from physical damage and pest attack. The collected samples were immediately transferred to the Nigerian Stored Products Research Institute (NSPRI), Hadeja Road, Kano. The pumpkin fruits were washed with running tap water, peeled, and manually sliced with a sterile stainless knife. The thickness of pumpkin slices was kept at 3 × 5 × 7 mm using a digital vernier calliper (accuracy: ±0.01 mm, range: 0–150 mm, model: Z22855 country: Molimex, Ltd., UK). Samples were immediately loaded for drying experiments.

Determination of Drying Rate

The drying rate was determined mathematically according to equation 12 [14]:

$$DR = \frac{M_i - M_f}{t} \tag{12}$$

Where
DR = drying rate (kg/h),
M_i = mass of product before drying (kg),
M_f = mass of the sample after drying (kg),
and t = drying time (8 h)

Determination of Moisture Content (MC)

Fruit slices were removed from the dryer during the drying process, and the moisture content was measured using a digital balance (model: 150 kg Diamond; accuracy: ±1 kg; range: 0–150 kg; country: Taiwan). Weight loss values were used to determine the fruit slices' moisture contents on a wet basis. After 15 minutes, the moisture content of the samples was measured and reported as the average sample weight per fresh sample weight. The moisture content was computed as the difference between dried and fresh samples using equation 13. Moisture content on the wet basis was calculated using the protocols described by Chen *et al.* [15]:

$$\text{MC}\ (w.b) = \frac{W_o - W_d}{W_o} \tag{13}$$

Where
MC $(w.b)$ is the moisture content of the sample on the wet basis,
W_o and W_d are sample weights before and after drying, respectively.

Drying Efficiency

The hybrid cabinet dryer's drying efficiency was determined by the amount of energy needed to remove the material's moisture content to the amount of energy provided by the electrical heating coil. The total energy needed to dry the material is the sensible and latent heat. Sensible heat is the energy needed to raise the food's temperature to a dryer temperature. The energy supplied includes the energy used by the blowers, exhaust fans, and heating coil. Equation 14 was used to determine the drying efficiency [16, 17].

$$\text{Drying efficiency} = \frac{Energy\ required\ to\ remove\ moisture}{Energy\ supplied\ by\ heating\ coil} \times 100 \quad (14)$$

Energy required to remove moisture: mass of water removed (kg) × latent heat of vaporization of water.

Energy supplied by the heating coil: power × time (kWh)

Shrinkage and Rehydration Ratio

During the drying process, food materials will experience shrinkage, as seen by changes in their dimensions. The pumpkin samples' dimensions were measured in the x, y, and z directions using a vernier calliper (accuracy: ±0.01 mm, range: 0–150 mm, model: Z22855, country: Molimex, Ltd., UK) before and after drying. The shrinkage was computed based on the changes in the dimensions. Equation 16 was used to get the percentage of shrinkage [18]:

$$Shrinkage\ (\%) = \frac{D_i - D_f}{D_i} \quad (15)$$

Where

D_i and D_f are the geometric mean diameters of samples before and after drying.

The geometric mean diameter (D) of pumpkin slices was calculated by using equation 16 [20]:

$$\mathrm{D} = (LWT)^{1/3} \quad (16)$$

Where

D is the geometric mean diameter in mm,

L is the length of the pumpkin slice in mm,

W is the width of the pumpkin slice in mm,

and T is the thickness of the pumpkin slice in mm.

The process of moistening a dried product is called rehydration, and it is a quality indicator for the majority of dry foods. It is an indicator of the cellular and structural disintegration that occurs when food is dehydrated [19]. The method outlined by Doymaz and Ismail [20] was used to calculate the dried pumpkin's rehydration ratio. At room temperature (28 ± 2 °C), five grams of dried pumpkin were submerged in distilled water. The rehydrated pumpkins were removed from the water and wiped with a paper towel to remove any remaining water from the surface. The weight of the rehydrated sample was recorded every 30 minutes until a constant weight was reached. Equation 17 was used to get the rehydration ratio [17]:

$$Rehydration\ ratio = \frac{Weight\ of\ rhydrated\ samole\ (g)}{Weight\ of\ dried\ sample\ (g)} \quad (17)$$

Quality Analysis after Drying

The dried pumpkin fruit slices were analysed to determine the quality of the dried flakes.

Proximate Analysis

The quality parameters assessed for the dried pumpkin slices were moisture, crude fibre, ash, crude protein, and carbohydrate contents, according to Magalhães *et al.* [21]. This technique determines a dried sample's percentages of moisture, ash, crude protein, fat, and carbohydrates. The Association of Official Chemists' guidelines were followed for doing the proximate analysis [22].

Enumeration of Total Bacteria on Dried Slices

The bacterial load of the dried pumpkin slice samples was determined using the spread plate method as reported by Saka *et al.* [23]. Briefly, the dried pumpkin sample was homogenized using a mechanical blender. The pulverized sample (1 g) was transferred into 9 mL of sterile distilled water to make the stock solution and was then serially diluted up to 10^{-5}. An aliquot of 0.1 mL was then plated onto a sterile plate of nutrient agar (Hi-media, India) and then incubated at 37°C for 18-24 hours. Distinct colonies were counted and expressed in colony-forming units per gram of sample.

Colour measurement

A colourimeter (Colour meter CM-200S) was used for the colour tests, according to Monalisa *et al.* [24]. The colour measurement was conducted according to (L^*, a^*, and b^*) colour parameters. The L^* value indicates the lightness of products; if less than 50, it means darkness, and a value higher than 50 indicates lightness. The a^* value describes the greenness or redness. A negative a^* value indicates greenness, while a positive value indicates redness. The b^* value defines the blueness or yellowness. A negative b^* value shows blueness, while a positive value shows yellowness. Equation 18 was employed to compute the total colour changes on the dried pumpkin slices [25]:

$$\Delta E = \sqrt{(L^* - L_O)^2 + (a^* - a_O)^2 + (b^* - b_O)^2} \quad (18)$$

Where

L_O, a_O, and b_O are the colour parameters of the fresh sample.

The chroma (which ranges from 0 to 60) is used to indicate the product's dullness or vividness and was calculated using equation 19 [26]:

$$Chroma = (a^{*2} + b^{*2})^{1/2} \quad (19)$$

The hue angle was determined according to equation 20. This parameter has been generally used in determining the colour parameters in fruits and vegetables [27]:

$$Huge\ angle = \tan^{-1}(b^*/a^*) \quad (20)$$

Statistical Analysis

All the drying experiments were carried out in triplicate from independent runs. The data was analyzed using IBM SPSS (version 26).

4. Conclusions

This study successfully developed and evaluated a hybrid solar dryer capable of providing stable, efficient, and hygienic drying conditions for pumpkin slices. The integration of solar energy with a DC-powered heating coil ensured continuous operation and improved thermal stability compared with traditional sun-drying.

A detailed analysis of the results will be included in the second part of the article.

References

[1] Belessiotis V. and Delyannis E.: Solar drying. Solar Energy, 2011, Vol. 85 (8), 1665 – 1691 https://doi.org/10.1016/j.solener.2009.10.001

[2] Kumar R.S.: Open Sun and Greenhouse Drying of Agricultural and Food Products: A Review. International Journal of Engineering Research & Technology (IJERT), March 2014, vol. 3, Issue 3, ISSN: 2278-0181.

[3] Ratnawati L. et al: The effect of the addition of pumpkin and carrot puree on the physicochemical and textural properties of Mocaf biscuit as a complementary food. IOP Conf. Series: Earth and Environmental Science, 2021, vol. 733, 012120, IOP Publishing. doi:10.1088/1755-1315/733/1/012120

[4] Doymaz I.: Infrared Drying of Sweet Potato (Ipomoea batatas L.) Slices. J. Food Sci. Technol, 2011, 49, 760–766. doi:10.1007/s13197-010-0217-8

[5] Fudholi A., Sopian K., Bakhtyar V., Gabbasa M., Othman M.Y., Mohd Hafidz Ruslan M.H.: Review of solar drying systems with air based solar collectors in Malaysia. ScienceDirect., 2015, volume 51, 1191-1204. https://doi.org/10.1016/j.rser.2015.07.026

[6] Gursewak Singh, G. S., Sadhna Arora, S. A. & Satish Kumar S. K.: Effect of mechanical drying air conditions on the quality of turmeric powder. Journal of Food Science and Technology (Mysore), 2010, *47*(3 PP-New Delhi), 347–350. https://doi.org/10.1007/s13197-010-0057-6

[7] Yadao, P. B. & Jachak S. R.: Study of different Turmeric Curing Processes. Journal of Emerging Technologies and Innovative Research, 2015, https://api.semanticscholar.org/CorpusID:136332835

[8] Sahay K. M. & Singh K. K.: Unit operation of Agricultural processing. Vikas Publishing House Pvt.Ltd, India, 1994.

[9] Mercer D. G.: An Introduction to The Dehydration and Drying of Fruits and Vegetables. Ontario, Canada: Department of Food Science, University of Guelph, 2014.

[10] Ajisegiri E. S. A., Alabadan B. A. and Uche I. K.: Development of an artificial dryer for yam chips. Proceedings of the 7th International Conference and 28th Annual General Meeting of the Nigerian Institution of Agricultural Engineers, ABU, Zaria, 2006, 28, 348.

[11] Eheim J. C., Irtwange S. V. & Obetta S. E.: Design and development of an industrial fruit and vegetable dryer. Research Journal of Applied Science, Engineering and Technology, 2008, 1(2), 44–53.

[12] Suherman S., Susanto E. E., Zardani A. W., Dewi N. H. R. & Hadiyanto H.: Energy–exergy analysis and mathematical modelling of cassava starch drying using a hybrid solar dryer. Cogent Engineering, 2020, *7*(1). https://doi.org/10.1080/23311916.2020.1771819

[13] Behera D. D., Mohanty R. C. & Mohanty A. M.: Experimental investigation of a hybrid solar dryer for vegetable drying with and without phase change material. Journal of the Brazilian Society of Mechanical Sciences and Engineering, May, 2024, volume 46, article number 303, 0–12. https://doi.org/10.1007/s40430-024-04876-0

[14] Matuam B., Edoun M., Kuitche A. & Zeghmati B.: Experimental evaluation of the thermal performance of dryer airflow configuration. International Journal of Energy Engineering, 2015, 5(4), 80–86. doi:10.5923/j.ijee.20150504.03

[15] Chen J., Zhou Y., Fang S., Meng Y., Kang X., Xu X. & Zuo X.: Mathematical modeling of hot air-drying kinetics of Momordica charantia slices and their color change. Advance Journal of Food Science and Technology, 2013, 5(9), 1214–1219. https://doi.org/10.19026/ajfst.5.3085

[16] Correia A. F. K., Loro A. C., Zanatta S., Spoto M. H. F. & Vieira T. M. F. S.: Effect of temperature, time, and material thickness on the dehydration process of tomato. International Journal of Food Science, 2015, Article ID 970724, 1–7. https://doi.org/10.1155/2015/970724

[17] Cisni F. M., Neethu K. C., Murali S., Delfiya D. S. A. & Ninan G.: Design and development of solar-electrical hybrid dryer and its performance evaluation using shrimps. Biomass Conversion and Biorefinery, 2023, 14, 25343–25356. https://doi.org/10.1007/s13399-023-04651-6

[18] Mohsenin N.N.: Physical properties of plant and animal materials, second ed. Gordon and Breach Science Publishers, New York, 1986.

[19] Patterson J., Kailasam S., Giftson H. & Immaculate J. K.: Effect of drying technologies on the biochemical properties of Stolephorus commersonnii. Food Quality and Safety , July, 2018, 153–158. https://doi.org/10.1093/fqsafe/fyy010

[20] Doymaz İ. & İsmail O.: Drying characteristics of sweet cherry. Food and Bioproducts Processing, 2011, 89(1), 31–38. https://doi.org/10.1016/j.fbp.2010.03.006

[21] Magalhães I. B., Pereira A. S. A. de P., Silva T. A. & Renato N. dos S.: Predicting the higher heating value of microalgae biomass based on proximate and ultimate analysis. Algal Research, 2022, 64, 102677. https://doi.org/10.1016/j.algal.2022.102677

[22] AOAC: *Official Methods of Analysis of AOAC International*, 21st Ed., 2019, AOAC, Gaithersburg, MD, USA

[23] Saka H. K., Ahmad F. U. & Abubakar A. A.: Microbiological quality assessment of ready-to-eat vegetables sold in Yankaba Market, Kano, Kano State, Nigeria. Dutse Journal of Pure and Applied Sciences, 2022, 8(3b), 163–169. https://doi.org/10.4314/dujopas.v8i3b.16

[24] Monalisa K, Bhuiyan JA, Islam MZ & Sayem ASM.: Boiling-induced changes in physicochemical, bioactive compounds, color, and texture properties of pumpkin (Cucurbita maxima). Food Science and Technology International, 2019, 26(4), 333–343. https://doi.org/10.1177/1082013219894402

[25] Bechoff A., Westby A., Menya G. & Tomlins K. I.: Effect of pretreatments for retaining total carotenoids in dried and stored orange-fleshed sweet potato chips. Journal of Food Quality, 2011, 34, 259–267. https://api.semanticscholar.org/CorpusID:55165664

[26] Bechoff A.: Original Research Article: Carotenoid stability during storage of yellow gari made from biofortified cassava or with palm oil. Journal of Food Composition and Analysis, volume 44, 2015, Issue June, 36-44. https://doi.org/10.1016/j.jfca.2015.06.002

[27] Crupi P, Milella RA, Antonacci D.: Simultaneous HPLC-DAD-MS (ESI+) determination of structural and geometrical isomers of carotenoids in mature grapes. J Mass Spectrom. 2010, Sep, 45(9), 971-80 https://doi.org/10.1002/jms.1794.