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Drying Temperature Effects on Drying Kinetics, Engineering, Microstructural and Phytochemical Profile of Cassava

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Abstract

Purpose – This study is contrived to investigate the effects of drying temperature on multiple characteristics of cassava which would be useful for the fabrication of post-harvest equipment and design of cassava plant layouts. The results obtained are employable by researchers, technologists and engineers for the modelling and optimized drying operation of cassava. Furthermore, this research is adoptable for the selection of processing parameters for cassava drying with the view of conserving the phytochemical quality of the crop.

Design/methodology/approach – Peeled cassava tubers were wet-cleaned, chipped and dried at temperatures of 40, 50 or 60°C, and effects of drying temperature on drying kinetics, engineering properties, microstructure, antioxidant and phytochemical profile were evaluated. Analytical techniques such as mechanical testing with Universal Testing Machine (UTM), Scanning

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Electron Microscopy (SEM), Fourier-Transform Infrared Spectroscopy (FTIR) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging test were conducted.

Findings – The Page model at 60°C was best suited among all kinetic models. Samples dried at 60°C also required less force and energy for distortion. Scanning electron microscopy of dried samples exhibited a proportionate increase in size and distortion of starch granules as drying temperature increased. The FTIR analysis indicated an improved phytochemical profile with as drying temperature increased; a trend also observed with the DPPH radical scavenging potential.

Originality/value – These results could provide information for fabrication of cassava processing equipment, selection of the preferable drying conditions based on individual requirements, quality change in relation to consumer acceptability, and phytochemical configuration.

Keywords: *Manihot esculanta*, mechanical strength, starch granules, FTIR spectroscopy

Introduction

Cassava (*Manihot esculanta*) is a root tuber crop representing a staple food and the main energy source for an average 1 billion people globally (Li et al., 2017). Cassava has carbohydrate-opulent roots which can be transformed into diverse products ranging from food grade to industrial starches, which makes cassava important economically. Cassava starch products are used as functional additives for thickening, stabilizing and binding purposes in food and non-food related products. They have the comparative advantage over other starches due to being gluten-free, making them applicable for processing of products to be consumed by gluten-allergy individuals (Ariwaodo et al., 2017).

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Functionality of starch granules can be attributed to their composition and structure. Starch contains varying quantities of amylose and amylopectin depending on its source (Peymanpour et al., 2016). Structurally, starch granules are semi-crystalline: possessing crystal and amorphous shape (Ren, 2017). A collection of semi-crystals forms in a 9-10 nm repeated distance exhibiting a lamella-like shape (Pérez and Bertoft, 2010). When viewed from a further 100-400 nm arrangement, they occur in granular rings, which in collection, form blockets (Bertoft, 2017). Understanding the relationship between processing of starch raw material and starch granules would provide useful information for process and product optimization.

Freshly harvested cassava roots begin microbial and physiological deterioration almost immediately after harvest and can only last for 3 days. This is due to its high moisture content, ~70%, available for microbial metabolism (Saravanan et al., 2016). Cassava drying is necessary for reduction of moisture content and eventual conversion into a more stable, durable material, of reduced volume, making its transportation easier, minimizing post-harvest waste, optimally reducing its naturally high hydrocyanic acid (HCN) content. and improving palatability (Saravanan et al., 2016). Cassava drying involves the concurrent interface conveyance of heat and mass (water vapor). In a typical air-drying operation for a food material, it is positioned within a closed environment in which hot air is circulated, causing evaporation of water from the body and a reduction in its moisture content.

Engineering properties are important in fabrication and operation of processing equipment for an agricultural material. Temperature, density and moisture content affect these properties, and adequate knowledge of their relationships is necessary for data generation as input required for the design, fabrication and operation of driers for the handling and processing of cassava (Adekanye et al., 2016). Food industries need sufficient understanding of physical and

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engineering properties of cassava for its utilization as a raw material. Proper knowledge of engineering characteristics is essential for equipment and machinery fabrication, and because they are the quickest and most familiar indicators of other properties and sensory attributes, composition and shelf-life (Oke et al., 2007; Ekwu et al., 2012).

Microstructure is a basic property influencing mass and energy transfer phenomenon and several physical properties of food materials which determines their perceived quality in terms of mechanical and sensorial attributes (Kulozik et al., 2003). The microstructural conformation of any food material is of paramount importance and should be optimally considered in the development and design of novel and functional food products with enhanced stability and sensory attributes (Kaufmann and Palzer, 2011). On another note, it has been scientifically linked to the bioavailability and release of concomitant nutrients in foods (Parada and Aguilera, 2007).

Deleterious effects of drying as a means of moisture removal in foods, especially with regards to their nutrients, has been a subject of concern for food processors in recent years. The rising demand for functional, and therapeutic food, requires food technologists to closely monitor changes in nutritional profile of foods during and after processing. Data explaining the correlation between drying temperature on engineering properties, microstructure phytonutrients and antioxidative capability of cassava are not readily available. This study was undertaken to evaluate the relationship between drying temperature and these cassava attributes.

Materials and methods

Mature, defect-free, cassava roots were obtained from a local market in Jalandhar city of Punjab, India. The cassava tubers were peeled, wet cleaned and cut into rectangular chips of identical dimensions of 60 mm (length), 10 mm (width) and 20 mm (thickness).

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The cassava pieces were optimally dried using an electrically powered tray dryer fabricated from a steel box, having a 1.05 W rating blower which controls drying air velocity. All oven drying operations occurred at a steady air flow velocity of 1.5 $m \cdot s^{-1}$, and drying operations were conducted until equilibrium moisture content was attained. Moisture decrease was monitored for every 30 min within a 2 h period with an electric weighing balance (Model PM 2000; Adventurer OHAUS, Meller, Switzerland). Data sets from different experimental drying runs were recorded as moisture ratio (MR) versus drying time (t). Engineering properties, microstructure, phytochemical and antioxidative strength of pieces were determined subsequent to drying.

Analysis of data due to drying was carried out with 3 common models (Roberts et al., 2008). From the slope and intercept of each curve, drying constants were determined. The equilibrium moisture content (M_e) was determined by extension of drying period till no quantifiable decrease in weight was detected. The chi square (χ^2), root mean square error (RMSE), and relative percentage error (PE) were the basic criteria for evaluation of the fitness of each model. Comparison of predicted and experimental moisture ratio was done by chi square and root mean square error (Robert et al., 2008; Addo et al., 2009).

Colors of dried samples were determined with a colorimeter (Color Tec PCMTM, Color associates, Inc., Clinton, NJ), using the Commission Internationale de l'Eclairage (CIE) L*, a*, and b* color scheme. The colorimeter was first systemized (L = 93.25, a = 00.97, b = -2.74) with a white paper, Business Xerox 80 $g \cdot m^{-2}$.

Sizes of dried chips at equilibrium for each drying temperature were determined. Their final definite dimensions length (L), width (W) and thickness (T) were determined using EssTe digital

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calipers Model number: 43219-94223 (Yisite Technology, Shenzhen**,** China). Weights of pieces were measured with the analytical balance.

Mechanical properties were determined with a Universal Testing Machine (UTM M500/25KN, Testometric, **Rochdale,** England). For cassava dried samples, the machine was operated under the pre-load off condition and at 25.00 $mm \cdot min^{-1}$ working speed. Parameters, and grouped varieties, illustrating response of cassava under compression were measured. Deformation, energy at peak and force were determined at peak and yield stages.

Micrographs were captured using a Scanning Electron Microscope SEM (Model 3020, ASPEX, **Pennsylvania, USA**) at an accelerating voltage of 15 kV, display magnification of 1000× and a microscopy depth of 100 µm.

Additionally, dried pieces were ground to powder with laboratory-grade mortar and pestle and analyzed with the Fourier Transform Infrared Spectrophotometer (FTIR-84, Shimadzu, Kyoto**,** Japan) at an absorption spectra range of 430 to 4210$\cdot cm^{-1}$, at a resolution of 4$\cdot cm^{-1}$ and for 12 scans.

The powders for each sample were individually centrifuged at 10000 x g for 5 min with methanol and the supernatant subjected to the 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging test (Ayaash et al., 2017), with few modifications. Briefly, 1 mL of DPPH (0.1 mM solubilized in 95% methanol) was incorporated into 250 µL of the methanolic extract in test tubes with a subsequent vigorous shaking and dark incubation for 30 min at room temperature. The methanol solvent was used as the blank and absorbance was spectrophotometrically determined at 517 nm. The antioxidative potential, which is directly related to the scavenging activity of each methanolic extract was computed with the formula of Elfahri et al. (2016).

Drying kinetics of cassava

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Cassava samples were dried from initial moisture content 137.3% (on dry basis) to final moisture content 15.3, 13.12 and 10.13% at 40, 50 and 60ºC respectively. The time required for the drying to attain equilibrium moisture content were 12, 10 and 8 hrs at 40, 50 and 60ºC respectively. According tostudies conducted byKumar, Jain and Garg (2010) and Chawla et al. (2008), it was specifically noted that a temperature of 5°C during drying will decrease the time required for drying. In the course of the study, the increase in drying temperature with a consequential increase in drying rate was found to be due to greater evaporation of moisture by the higher drying air temperature at the interface between food and air. From the drying curve (**figure 1**), it was observed that the drying of cassava samples exhibited the characteristic moisture desorption behavior. An initial high rate of moisture removal was followed by a slower rate of moisture removal at later stages. This behavior is due to the variations in the tenacity with which water is held in cassava. Similar results were also reported by Aghbashlo et al.(2011) and Doymaz (2004) for carrots and mulberry. The values of drying rate constants acquired from the three models-Page, Lewis and Henderson-Pabis are given in **Table 2**. Drying rate constant was found to increase with increase in drying temperature. Similar results were also observed by Roberts, David and Padilla-Zakour, 2016, in a study involving drying of grape seeds.

Evaluation of models

The moisture ratio (MR) was obtained from the conversion of the experimental moisture content acquired in the course of drying operation and then subjected to the three different models (Page, Lewis and Henderson-Pabis). On the basis of statistical parameters, page model at 60 ºC was found to be best fitted to the cassava drying as shown in Table 3. Similar results were reported by the Abano and Sam-Amoah (2011) and Darvishi, Banakar, and Zarein (2012) for banana and carrot drying kinetics.

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It can be inferred from Table 3 that the RMSE, chi square ($\chi 2$) and standard error (PE) values are lower in Page model and 60 ºC is the best temperature for effective drying. The comparison between the predicted and experimental values for the best fitted model (Page Model) is given in **figure 2**. The curves show very close correlation between the predicted and the experimental moisture ratio of the cassava at 60 ºC.

Size and Density

True density is known scientifically to have an inverse relationship with temperature except for the case of substances like water which exhibit an anomaly. Food materials, generally composed of fluids and dry matter, in the course of the drying operation, starch granules undergo the collapse and/or shrinkage effect which leads to significant decrease in porosity, volume and density (Qui et al., 2015). Drying reduces the mass by loss of water as vapor and since mass has a direct relationship with density, reduction in density occurs.

The results obtained from this study (Table 4) showed a more favourable decrease in mass and volume with an increase in drying temperature. This is due to the loss of water, which is enhanced by drying at higher temperatures.

Romulli, Abass and Müller (2016) in a research study regarding the effects of pneumatic drying on the physical properties of cassava grits obtained similar results. The average mesh size of the grits was observed to reduce from 0.75 mm before drying to 0.17 mm after drying. The study of size change effected by drying is important, as it provides data for the development of mathematical models needed for the fabrication of different processing equipment (Altan, Mccathy, Maskan, 2008)

Color

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The color indicates the intensity of white light (L), redness (a), yellowness (b) and Chroma (C). The results obtained for color are displayed in Table 5. Intensity of white light (L) was found to be highest for the 40 °C samples (74.35±0.021) amongst all treatments. Results obtained for the L values revealed that drying at higher temperature cause a decrease in whiteness. This is possibly due to the onset of browning of the starch granules which is enhanced by high temperature treatment (Altan, Mccathy, Maskan, 2008). Similar results were obtained by Mesquita, Leonel and Mischan (2013), in a study about the influence of extrusion cooking on the physical properties of cassava starch and flaxseed composite flour**.** Results of L values showed a profound difference before (94.71) and after (average of 66.4) the high temperature extrusion treatment.

The L values of processed cassava at any production stage are important as they determine the overall acceptability of the final product by the consumer. Abacha; a boiled, sliced and dried cassava food product, native to Nigerian indigenes was studied by Ekwu, Uvere and Chinwere (2012) regarding its quality in its fresh and dried state. Sensory analysis was performed on the basis of color acceptability, the freshest product with a higher degree of whiteness was found to have more preference by the sensory panel.

The b* value, which specifies the yellowness intensity was found to be highest for 60 °C samples samples and lowest for samples oven dried at 40°C (Table 5). Accordingly, drying at higher temperatures produced results with higher values of yellowness. These trends could be due to the promotion of color-changing reactions in the starch granules by heat and light (Kikuchi, Ohtake, and Tanaka, 2012). Yi et al.(2011) in a research study on cassava successfully isolated 10 phenolic compounds, namely; Scopoletin, isovanillin, 6-deoxyjacareubin, p-coumaric acid, pinoresinol, syringaldehyde, ficusol, ethamivan and balanophonin. Other compounds such as

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scopoletin, quercetin, tyrosine, caffeic acid, ascorbic acid, mallic acid, and glucose have been previously isolated from cassava roots by Lalaguna (2003). Subjection of these compounds to heat and/or light could be the reason for the trend in yellowness results obtained (Kikuchi, Ohtake, and Tanaka, 2012). These findings are in consistency with results obtained by Akintunde and Tunde-Akintunde(2013) in which effects of the sun and solar drying methods on some physical properties of cassava starch have been reported. Their results showed that sun dried (at relatively higher temperature) starch extracts had higher values for yellowness than oven dried ones.

The a* values which signifies redness was observed to be directly proportional to the drying temperature. Using the same temperatures (40, 50 and 60 °C) for the oven drying procedure, Marcel, Kuitche and Giroux (2013), in a research study about the effects of heating and drying mechanism for pineapple color change reported that redness increased with a corresponding rise in drying temperature. This trend, however differs from the results obtained by Zielinska and Markowski (2012) on the evaluation of the impacts of drying and rehydration on the color of carrots. Temperatures of 60, 70, 80 and 90 °C were used for drying and their results showed a higher overall redness of carrots dried at lower temperatures than higher ones. They attributed the trend to a higher degradation of β-Carotene when drying at higher temperatures.

Engineering Properties

The results of the mechanical properties (force, deformation and energy at peak- and break phases, stress, strain and mathematically derived young modulus) of samples under compression are shown in Table 6. Force and energy at peak are the input quantities required to strain a material to its point of yield. Deformation at peak is the overall change in dimension at the yield point. The breaking point is the loading point where the material experiences rupture.

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Readings obtained showed that samples dried at lower temperature having higher moisture content required more force and energy to reach the peak and breaking points. Samples dried at 60 °C were found to have low values for force, deformation and energy at peak and break points. Oven dried samples at 40°C had the highest value for all the mechanical properties evaluated.

A similar study was conducted by Ishiwu, Obiegbuna and Igwe (2015) involving the effect of drying on the breaking strength of sliced cassava chips at different temperature conditions. Their results follow a similar course with the ones obtained in this study indicating a proportional relationship between breaking force and moisture content for most of the examined chips. This effect may be due to the shrinkage effect of water loss caused by drying. Cassava has a relatively high moisture content of about 65-70 %. The loss of a large fraction of the containing water may lead to shrinkage of the starch granules making them easier to rupture. Furthermore, drying at higher temperature creates moisture and temperature gradients across the inner and outer layers of the material undergoing drying (Lewicki and Pawlak, 2003). These gradients build up internal stresses and cracks causing disruptions in the structural configuration of food materials (Sadjad, and Saeid, 2014).This process may be the rationale behind the decrease in energy and force required at yield and break with a proportionate rise in drying temperature. Contradicting results were obtained by Akinoso, Aremu and Balogun (2014) in a study carried out on two varieties of Kolanut (*Cola nitida* and *Cola acuminate).* An inverse relationship was obtained between drying time and temperature on the mechanical strength.

Microstructure

The images obtained from the SEM micrographs (**figure 3**) showed an increase in distortion of the size and shape of the cassava starch granules with a corresponding increase in drying temperature. The distortion is due to the gelatinization of the starch granules on heating.

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Gelatinization has been defined as a transitional phase undergone by starch granules when subjected to thermal treatment in the presence of water, which causes their hydrated swelling and loss of molecular and crystalline order (Alcázar, Sylvia and Meireles, 2015).A similar phenomenon was also shown in the results of the study conducted by Sjoo, Eliasson and Autio (2009) involving the comparison of various microscopic analytical techniques for potato starch. Their SEM micrographs for cooked potato samples showed a complete bursting disruption of the potato cell walls after undergoing gelatinized swelling on cooking. Rosell et al. (2013) in a study regarding structural changes induced by heating and mechanical treatment of wheat dough, examined the microstructure of the dough starch after each treatment. A gelatinized disruption of the wheat starch granules caused by heating was also shown from the SEM micrographs taken in the course of their study.

The micrographs for the 50 and 60 °C dried samples show the formation of a fibrous layer within the starch granules along with the gelatinization effect. This effect is more pronounced the 60 °C samples. The formation of fibrous residue during drying is similar to the cassava micrograph obtained by Varsino and Garcia (2016). Their characterization of the chemical composition showed that the fiber is mainly composed of starchy carbohydrates. The presence of a fibrous layer constituted the difference which is similar to the results obtained by Deng and Zhao, (2008) who examined the scanning electron micrographs on the surface of fresh and dried samples. They attributed the continuous moisture, osmotic and thermal gradient built up in the apple cell walls causing their deformation, folding and eventual structural collapse.

FTIR phytochemical analyses

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The results obtained are shown in **figures 4a-c** and the peak interpretations shown in Table 7**.** As indicated, drying at higher temperatures induced the synthesis of more phytonutrients. The O-H group, which signifies the polyphenolic compounds was found to be most available in the 60 °C dried samples with intensities of 99.587 and 95.496 % respectively unlike the 40 °C with one O-H stretch, having an intensity of 93.812 %. The drying temperatures of 50 and 60 °C also induced the synthesis of isothiocyanate, alkene and aromatic amine compounds which are absent in the 40 °C dried samples. However, the 40 °C showed the presence of C=C bending which is absent in other samples. These results indicate the thermally-induced syntheses of multiple compounds at higher drying temperatures. The increase in the polyphenolic and for example, is desirable for the isolation of antioxidative components from cassava. The FTIR-peak spectra obtained in this study are similar to those reported by Mena-Durán et al., 2019 in the investigation involving the FTIR analysis of cassava hydrochars. O-H, C-O and C=C peaks for the thermally degraded samples were obtained at 3300, 1200 and 2925/cm respectively.

Antioxidative functionality

The DPPH radical scavenging test further confirmed the results obtained from the FTIR analysis. As shown in **figure 5** the antioxidative potential increased with drying temperature for the range of temperatures adopted in this study. Typically, processing of plant-based foods at high temperatures induce thermal degradation of concomitant antioxidant with an imminent reduction in the antioxidative functionality. However, thermal processing at mild temperatures, usually about 50-60 °C has been experimentally shown to improve the antioxidative profile of starches probably due to easier release of polyphenols or on the basis of the products released from Maillard reaction at such temperatures (Bennett et al., 2011).

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Similar antioxidative results were obtained by Rodríguez et al., 2016 for the total flavonoid and total phenolic contents of berry subjected to drying at temperatures ranging from 40-80 °C. Maximum values of 4162 ± 163 mg GAE 100 /g dm and 3450 ± 21 mg QE 100 /g dm were reported for the total phenolic and total flavonoid contents at 60 and 70 °C respectively. Vimala et al., 2010 also conducted a study involving the comparative effects of oven drying (at 50 °C), frying, and boiling on the total carotenoid content of cassava. Their results showed that oven drying at 50 °C, being the mildest of the treatments offered the highest β-carotene and total carotenoid content retention of 63.90–94.53% and 54.70–84.01% respectively.

The comparative effects of increasing drying temperature (40, 50 and 60 °C) for cassava on the drying kinetics, engineering, microstructural, phytochemical and antioxidative profile of cassava has been investigated in this study. Results obtained revealed that drying at 60 °C was most suitable on the basis of the drying kinetics and engineering attributes. However, the SEM micrographs obtained showed that more distortions occurred to the cassava starch granules at this temperature relative to the 40 °C drying. The FTIR analysis showed more peaks with higher intensities for 50 and 60 °C signifying the thermally-induced synthesis of more compounds during drying. The 60 °C drying was also found to be superlative in relation to the antioxidative enhancement of the cassava samples. The results obtained from this scientific investigation is serviceable for food engineers for the optimized fabrication of processing equipment and plant design for cassava drying and other post-harvest handling operations.

Conflicts of Interest

Authors state that there are no conflicts of interest.

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References

Abano, E.E. and Sam-Amoah, L.K. (2011), "Effects of different pretreatments on drying characteristics of banana slices",*Journal of Engineering and Applied Sciences*, Vol. 6, pp. 121-129

Adekanye, T., Adegbenro, V.O. and Saliu, K.R. (2016),"Development of maize - on - cob- dryer for small scale farmers",*Scientia Agriculturae.*Vol. 14, pp. 172 - 178. http://dx.doi.org/10.15192/PSCP.SA.2016.14.1.172178.

Adetunji, A.R., Isadare, D.A., Akinluwade, K.J., and Adewoye. O.O. (2015),"Waste-to-Wealth applications of cassava–a review study of industrial and agricultural applications",*Journal of Advanced Research,* Vol.4 No. 4, pp. 212-229. https://doi.org/10.9734/AIR/2015/15417

Addo, A., Bart-Plange, A. and Boakye, M.D. (2009) "Drying characteristics of cap and stem of mushroom",*Journal of Science and Technology*,Vol. 29, pp. 88–94. https://doi.org/10.4314/just.v29i2.46226

Aghbashlo, M., Kianmehr, M., Arabhosseini, A. and Nazghelichi, T. (2011),"Modelling the carrot thin-layer drying in a semi-industrial continuous band dryer",*Czech Journal of Food Science*, Vol. 29, pp. 528-538. https://doi.org/10.17221/158/2010-CJFS

Akinoso, R., Aremu, A.K. and Balogun, I.S. (2014),"Some physical properties of Kola nuts – a response surface approach",*International Agrophysics*, 28, pp. 251-255. https://doi.org/10.2478/intag-2014-0014

ISSN:0971-1260
Vol-22-Issue-16-August-2019

Akintunde, B. O. and Tunde-Akintunde, T.Y. (2013),"Effect of drying method and variety on quality of Cassava starch extracts", *African Journal of Food, Agriculture and Nutritional Development*,Vol. 13, pp. 8351-8367.

Alcázar A., Sylvia, C. and Meireles, M.A. (2015),"Physicochemical properties, modifications and applications of starches from different botanical sources",*Food Science and Technology Campinas*. Vol. 35, pp. 215-236. http://dx.doi.org/10.1590/1678-457X.6749.

Altan, A., Mccathy, K. L. and Maskan, M. (2008),"Twin-screw extrusion of barley-grape pomace blends: extrudate characteristics and determination of optimum processing conditions",*Journal of Food Engineering*,Vol. 89, pp. 24-32. https://doi.org/10.1016/j.jfoodEngineering2008.03.025.

Ariwaodo, C., Ezeama, C. and Titus, U.N.(2017),"Morphology, rheology and functional properties of starch from cassava, sweet potato and cocoyam",*Asian Journal of Biology*, 3(3):1-13. http://dx.doi.org/10.9734/AJOB/2017/34587

Ayyash, M., Al-Nuaimi, A.K., Al-Mahadin, S. and Liu. S.Q. (2017),"*In vitro* investigation of anticancer and ACE-inhibiting activity, α-amylase and α-glucosidase inhibition, and antioxidant activity of camel milk fermented with camel milk probiotic: a comparative study with fermented bovine milk",*Food Chemistry*, doi: http://dx.doi.org/10.1016/j.foodchem. 2017.06.149.

Bennett, L.E., Jegasothy, H., Konczak, I., Frank, D., Sudharmarajan, S. and Clingeleffer, P.R. (2011),"Total polyphenolics and anti-oxidant properties of selected dried fruits and relationships to drying conditions",*Journal of Functional Foods*,Vol. 3, pp. 115-124.

Bertoft, E. (2017),"Understanding starch structure: recent progress",*Agronomy Journal*,Vol. 7, pp. 56. http://dx.doi.org/10.3390/agronomy7030056.

ISSN:0971-1260
Vol-22-Issue-16-August-2019

Chawla, C., Kaur, D., Oberoi, D. and Sogi, D. (2008), "Drying characteristics, sorption isotherms, and lycopene retention of tomato pulp",*Drying Technology,*Vol. 26, pp. 1257-1264. https://doi. org/10.1080/07373930802307225.

Darvishi, H., Banakar, A. and Zarein, M. (2012),"Mathematical modelling and thin layer drying kinetics of carrot slices",*Global Journal of Science Frontier Research,*Vol. 12: 57-64.

Deng, Y. and Y.Y. Zhao. 2007. Effects of pulsed-vacuum and ultrasound on the osmo-dehydration kinetics and microstructure of fuji apples. J. Food EngineeringVol. 85, pp. 84-93. https://doi.org/10.1016/j.jfoodEngineering2007.07.016.

Donkor, E., S. Onakuse, J. Bogue, and R.I. Carmenado. 2017. The impact of the presidential cassava initiative on cassava productivity in Nigeria: implication for sustainable food supply and food security. Cogent Food Agric. Vol. 3 No. 1, pp. 1368857. https://doi.org/10.1080/23311932.2017.1368857.

Doymaz, I. 2004. Drying kinetics of White Mulberry. J. Food EngineeringVol. 61, pp. 341-346. https://doi.org/
10.1016/S0260-8774(03)00138-9.

Elfahri, K.R., T. Vasiljevic, T. Yeager, and O.N. Donkor. 2016. Anti-colon cancer and antioxidant activities of bovine skim milk fermented by selected *Lactobacillus helveticus* strains. J. Dairy ScienceVol. 99 No. 1, pp. 31-40. doi:10.3168/jds.2015-10160

Ekwu, F.C., P.O. Uvere, and O.M. Chinwero. 2012. Quality of 'abacha' from fresh cassava roots and dried chips. Nig. Food J. Vol. 30, pp. 124-130. https://doi.org/10.1016/S0189-7241(15)30021-7.

ISSN:0971-1260
Vol-22-Issue-16-August-2019

Ishiwu, C.N., J.E. Obiegbuna, and E.C. Igwe. 2015. Effect of process variables on some physical properties and hydrogen cyanide content of dried cassava slices “abacha”,. J. Food Process TechnologyVol. 6, pp. 471. https://doi.org/10.4172/2157-7110.1000471.

Kikuchi, T., Y. Ohtake, and K. Tanaka. 2012. Discoloration phenomenon induced by the combination of phenolic antioxidants and hindered amine light stabilizers. Nippon Gomu Kyokaishi. Vol. 85, pp. 283-288. https://doi.org/10.2324/gomu.85.283.

Krokida, M. K., Karathanos, V. T., Maroulis, Z. B. and Marinos-Kouris, D. (2003),“Drying kinetics of some vegetables”,*Journal of Food Engineering*,Vol. 59, pp. 391-403. https://doi.org/10.1016/S0260-8774(02)00498-3.

Kulozik, U., Tolkach, A., Bulca, S. and Hinrichs, J (2003),“The role of processing and matrix design in development and control of microstructures in dairy food production – A survey”, *International Dairy Journal*,Vol. 3, pp. 621-630. https://doi.org/10.1016/S0958-6946(03)00141-9.

Kumar, R., Jain, S. and Garg, M.K. (2010),“Drying behaviour of rapeseed under thin layer conditions”,*Journal of Food ScienceTechnology*,Vol. 47, pp. 335-338. https://doi.org/10.1007/s13197-010-0054-9.

Lalaguna, F. (1993),“Purification of fresh cassava root polyphenols by solid-phase extraction with Amberlite XAD-8 resin”,*Journal of Chromatography A*,Vol. 657, pp. 445-449. https://doi.org/10.1016/0021-9673(93)80301-N.

Lewicki, P.P. and Pawlak, G. (2003),“Effect of drying on microstructure of plant tissue”,*Drying Technology*,Vol. 21, pp. 657-683. https://doi.org/10.1081/DRT-120019057.

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Li, S., Cui, Y., Zhou, Y., Luo, Z., Liu, J. and Zhao, M.(2017), "The industrial applications of cassava: Current status, opportunities and prospects",*Journal of Food Science and Agriculture*,Vol. 97, pp. 2282-2290. http, pp. //dx.doi.org/10.1002/jsfa.8287.

Marcel, E., Kuitche, A. and Giroux, F. (2014),"Effect of thermal process and drying principle on color loss of pineapple slices",*American Journal of Food Science and Technology*,Vol. 2, pp. 17-20. https://doi.org/10.12691/ajfst-2-1-3.

Mena-Durán, C.J., Quintana, P., Barbosa, R., Baas,J.M. and Escobar, B. (2019),"Characteristics of hydrochars prepared from cassava residues using different aqueous media",*Waste Biomass Valorization*,pp.1-6doi, pp. 10.1007/s12649-018-00561-1.

Mesquita, C.B., Leonel, M. and Mischan, M.M. (2013)"Effects of processing on physical properties of extruded snacks with blends of sour cassava starch and flaxseed flour",*Food Science and Technology*,Vol. 33, pp. 404-410. http, pp. //dx.doi.org/10.1590/S0101-20612013005000073.

Oke, M.O., Awonorim,S.O., Sanni,L.O., Akanbi, C.T. and Abioye, A.O. (2007), Determination of some engineering properties of sweet potato cuts as a function of temperature.*Journal of Food Technology*,Vol. 5, pp. 66-70.

Palzer, S. and Kaufmann, F.M. (2011),"Food structure engineering for nutrition, health and wellness",*Procedia Food Science*,Vol. 1,pp.1479-1486. 10.1016/j.profoo.2011.09.219.

Parada, J. and Aguilera, J.M. (2007),"Food microstructure affects the bioavailability of several nutrients", Journal of Food Science,Vol. 72. R21-32. 10.1111/j.1750-3841.2007.00274.x.

Pérez, S. and Bertoft, E. (2010),"The molecular structures of starch components and their contribution to the architecture of starch granules: A comprehensive review",*Stärke*,Vol. 62, pp. 389-420. https://doi.org/10.1002/star.201000013.

ISSN:0971-1260
Vol-22-Issue-16-August-2019

Peymanpour, G., Marcone, M., Ragaee, S., Tetlow, I., Lane, C.C., Seetharaman, K. and Bertoft, E. (2016),"On the molecular structure of the amylopectin fraction isolated fromhigh-amylose maize starches",*International Journal of Biological Macromolecules*,Vol. 91, pp. 768–777. https://doi.org/10.1016/ J.ijbiomac.2016.06.029

Qiu, J., Seddik, K., Alex, M., Gerard, V., Maarten S. and Cristhian, A. (2015),"Porosity, bulk density, and volume reduction during drying, pp. review of measurement methods and coefficient determinations",*Drying Technology*,Vol. 33, pp. 1681-1699. https://doi.org/10.1080/ 07373937.2015.1036289.

Ren, S. (2017),"Comparative analysis of some physicochemical properties of 19 kinds of native starches",*Stärke,* Vol. 68, pp. 1600367. https://doi.org/10.1002/star.201600367.

Roberts, J., David, R.K. and Padilla-Zakour, O. (2008),"Drying kinetics of grape seeds",*Journal of Food Engineering*,Vol. 89, pp. 460-465. https://doi.org/10.1016/j.jfoodEngineering2008.05.030.

Rodríguez, K., Ah-Hen, K.S., Vega-Gálvez, A., Vásquez,V., Quispe-Fuentes,I., Rojas,P. and Lemus-Mondaca, R. (2016), "Changes in bioactive components and antioxidant capacity of maqui, *Aristotelia chilensis* [Mol] Stuntz, berries during drying",*Food Science and Technology,*Vol. 65, pp. 537-542. doi, pp. 10.1016/j.lwt.2015.08.050.

Romuli, S., Abass, A. and Müller, J. (2016),"Physical properties of cassava grits before and after pneumatic drying",*Journal of Food Process Engineering*,Vol. 40 No. 2, e12397. https://doi.org/10.1111/jfpe.12397.

Rosell, C., Altamirano-Fortoul, R., Don, C. and Dubat, A. (2013),"Thermo-mechanically induced protein aggregation and starch structural changes in wheat flour dough",*Cereal Chemistry*,Vol. 90, pp. 89. http, pp. //dx.doi.org/10.1094/CCHEM-05-12-0056-R.

ISSN:0971-1260
Vol-22-Issue-16-August-2019

Sadjad, A. andSaeid, M. (2014),"Effect of drying temperature on mechanical properties of dried corn",*Drying Technology,*Vol. 32, pp. 774-780. https://doi.org/10.1080/07373937.2013.845203.

Saravanan, R., Ravi, V., Stephen, R., Thajudhin, S. and George, J. (2016),"Post-harvest physiological deterioration of cassava (*Manihot esculenta*) - A review",*Indian Journal of Agriculture,*Vol. 86, pp. 1383-1390.

Sjöö, M, A. Eliasson, and Autio, K. (2009),"Comparison of different microscopic methods for the study of starch and other components within potato cells",*GBS Food,*Vol. 3, pp. 39-44.

Versino, F., and García, M. (2014),"Cassava (*Manihot esculenta*) starch films reinforced with natural fibrous filler",*Industrial Crops Production,*Vol. 58, pp. 305-314. https://doi.org/10.1016/j.indcrop.2014.
04.040.

Vimala, B., Thushara, R., Nambisan,B. and Sreekumar.J.(2010),"Effect of processing on the retention of carotenoids in yellow-fleshed cassava (*Manihot esculenta* Crantz) roots",*International Journal of Food Science and Technology,*Vol. 46 No. 1, pp. 166-169. doi, pp. 10.1111/j.1365-2621.2010.02478.x.

Yi, B., Hu, L., Mei, W., Zhou, K., Wang, H., Luo, Y., Wei, X. and Dai, H. (2011),"Antioxidant phenolic compounds of cassava (*Manihot esculenta*) from Hainan",*Molecules,*Vol. 16, pp. 10157-10167. https://doi.org/10.3390/molecules161210157.

Zielinska, M. and Marek, M. (2012),"Color characteristics of carrots: effect of drying and rehydration",*International Journal of Food Properties,*Vol. 15, pp. 450-466. https://doi.org/10.1080/10942912.2010.489209.

ISSN:0971-1260
Vol-22-Issue-16-August-2019

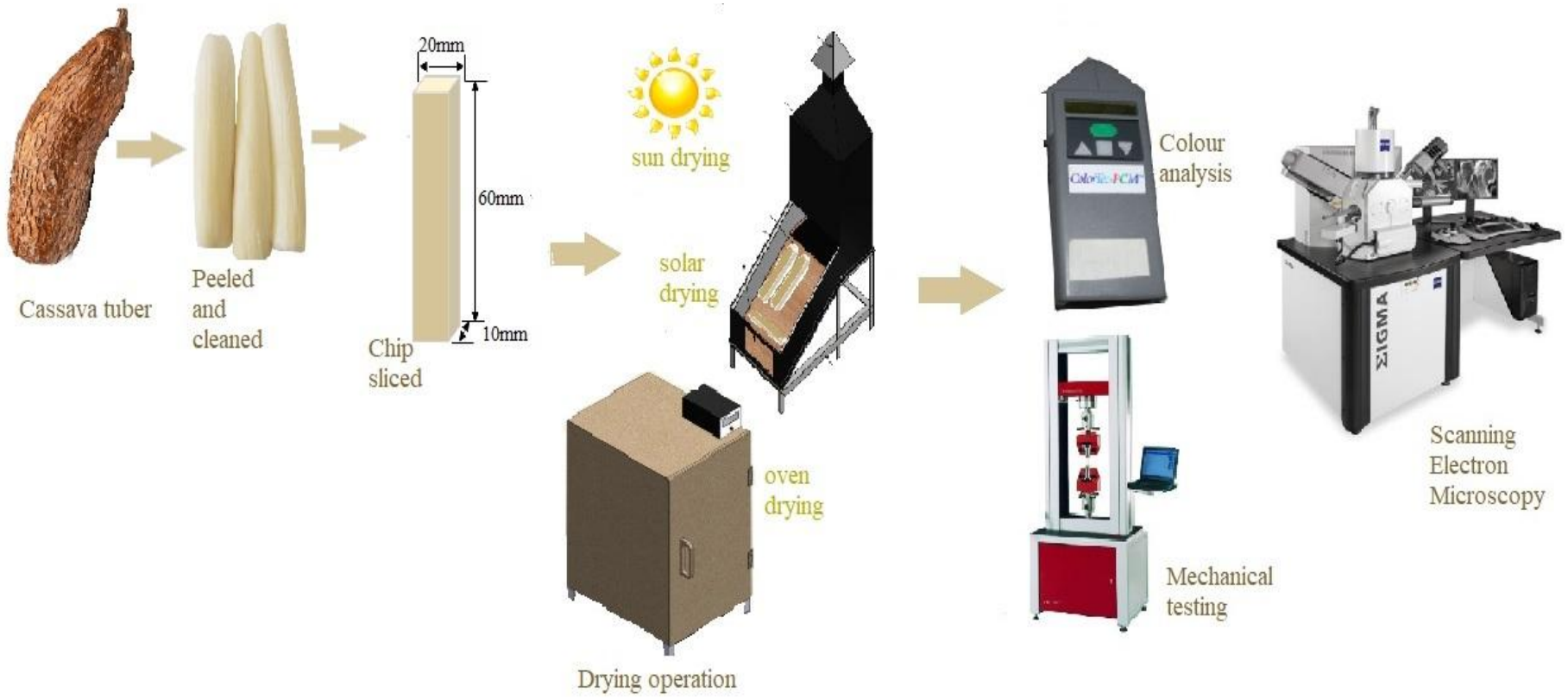

Figure 1: Summarized flow diagram for research methodology

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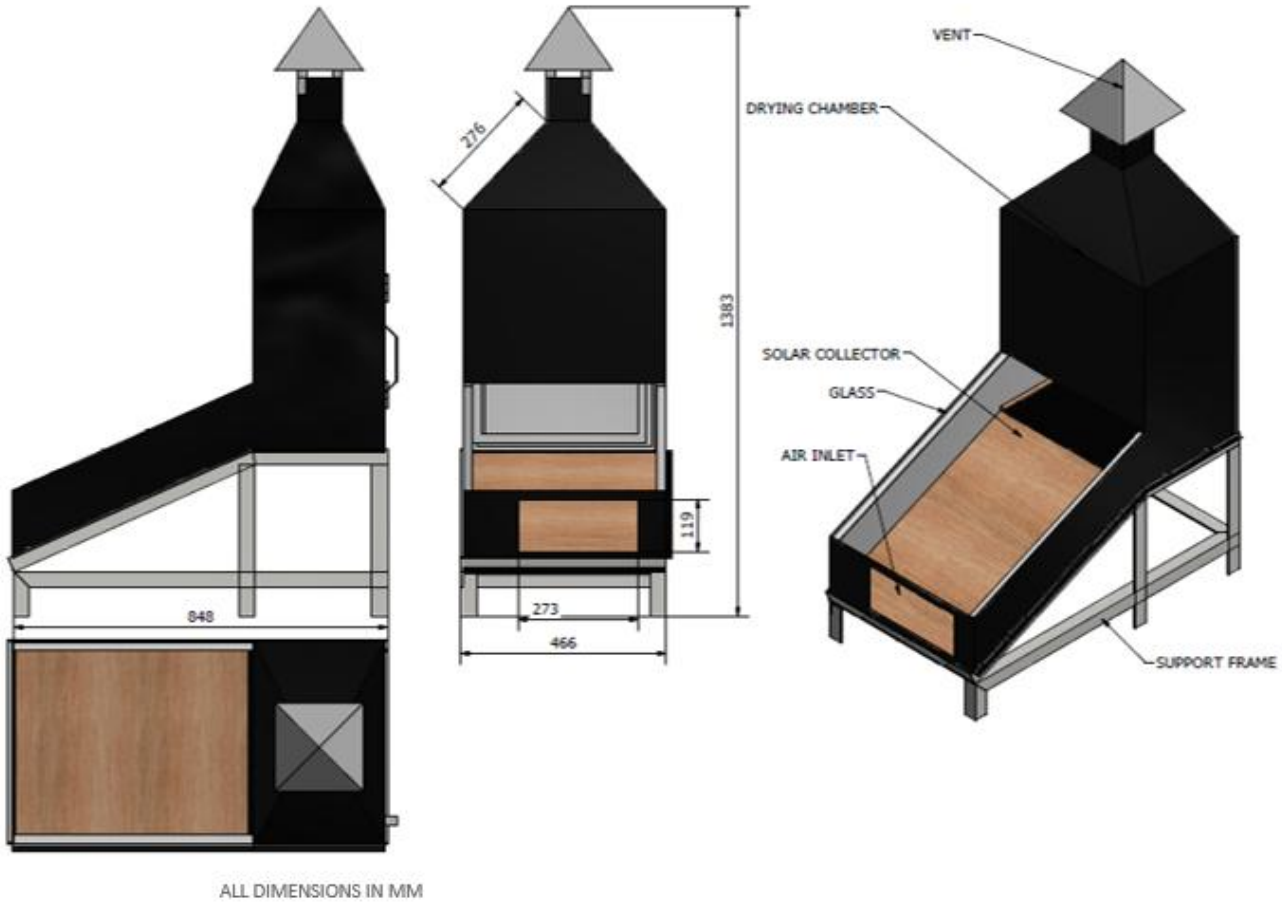

Figure 2: Schematic diagram of a single collector solar dryer

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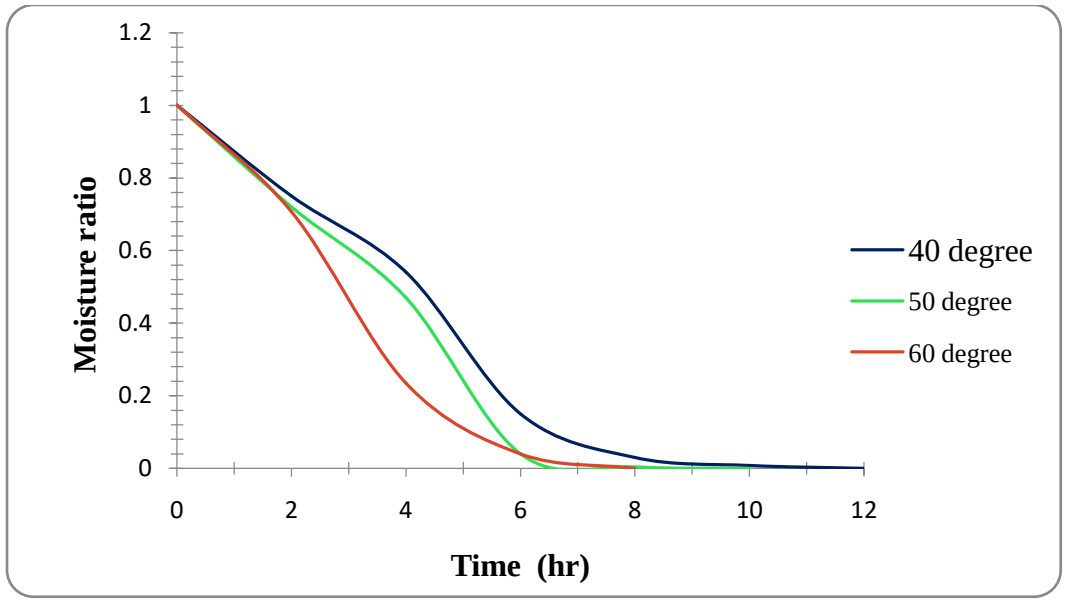

Figure 3: Moisture ratio vs time at different time interval for different temperature

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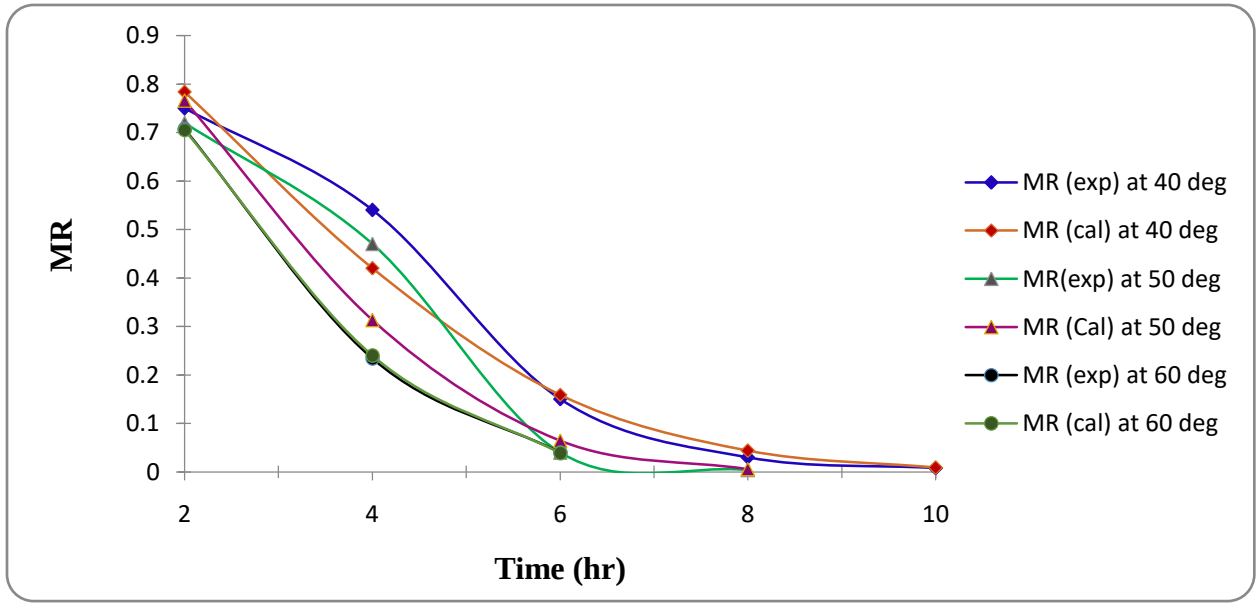

Figure 4: Experimental and predicted values of Moisture ratio at varying times for the best fitted model (Page Model)

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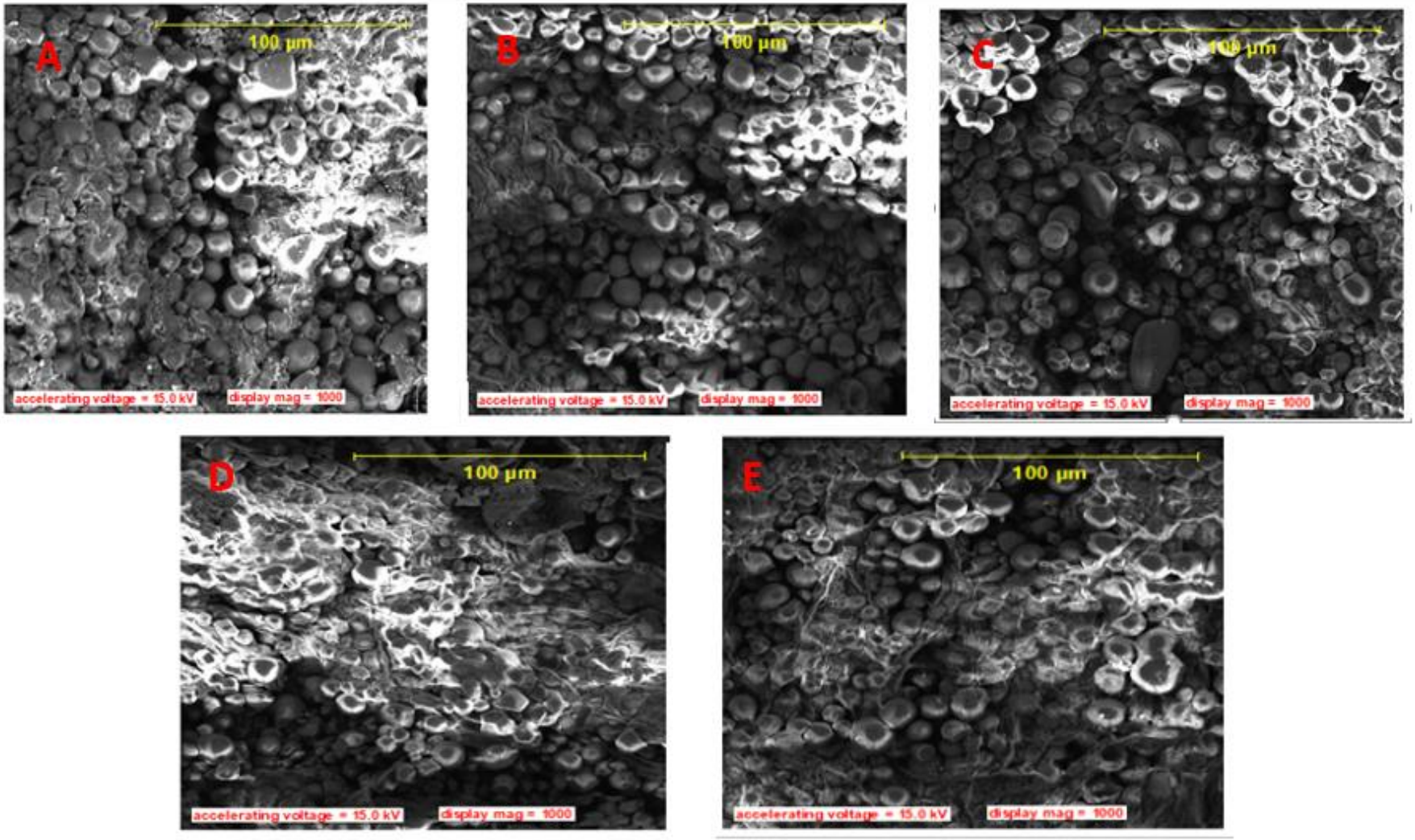

Figure 5: Micrographs for dried samples

A- Oven drying at 60°C, B- Oven drying at 50°C, C- Oven drying at 40°C, D- Solar drying, E- Sun drying

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Table 1: Empirical constants of Page, Lewis and Henderson-Pabis model

	Temp (°C)	Page equation			Lewis equation		Henderson-Pabis equation		
		K(min^{-1})	N	R^2	K(min^{-1})	R^2	K(min^{-1})	α	R^2
Cassava	40	0.0684	1.8359	0.9707	0.5489	0.9558	0.5986	1.3648	0.9740
	50	0.0614	2.1214	0.9610	0.7263	0.8729	0.9020	2.0545	0.9850
sample	60	0.0853	2.0322	0.9998	0.6752	0.9788	0.7178	1.1991	0.9827

R^2 (Regression coefficient), k (drying rate constant), a and N (constants)

Table 2: Statistical results obtained from different thin-layer models

	Temp (°C)	Page equation			Lewis equation			Henderson-Pabis equation		
		RSME	χ^2	PE	RSME	χ^2	PE	RSME	χ^2	PE
Cassava	40	0.0561	0.0099	2.40	0.0563	0.0063	2.45	0.2484	0.1703	12.75
	50	0.0820	0.0270	4.60	0.3199	0.2160	18.83	0.2822	0.1722	8.17
sample	60	0.0036	0.0001	0.30	0.2760	0.1354	21.63	0.2621	0.1248	4.16

RMSE (Root Mean Square Error), SE (Standard Error), χ2 (Reduced Chi Square)

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Table 3: Physical properties of dried sample

Sample	Length (mm)	Width (mm)	Breadth (mm)	Volume (mm^3)	Mass (g)	Density (g/mm^3)
A	41.25±0.03[a]	8.54±0.027[a]	17.24±0.021[a]	6075.4±14.50[a]	3.61±0.262[a]	5.94E-4±7E-4[a]
B	43.82±0.15[b]	8.57±0.021[d]	17.30±0.01a[b]	6494.8±20.89[a]	3.64±0.979[a]	5.61E-4±9E-7[b]
C	43.05±0.01[c]	9.28±0.015[b]	19.23±0.015[c]	8381.6±12.52[c]	3.79±0.949[c]	4.52E-4±10E-4[c]
D	46.23±0.01[d]	9.40±0.006[c]	19.96±0.01[d]	8303.0±6.12[d]	4.08±0.636[d]	4.91E-4±10E-7[d]
E	46.23±0.01[d]	9.96±0.006[d]	19.96±0.01[d]	9003.4±8.38[e]	4.10±0.01[d]	4.55E-4±15E-7[e]

A- Oven drying at 60°C, B- Oven drying at 50°C, C- Oven drying at 40°C, D- Solar drying, E- Sun drying

Table 4: Color composition of dried samples

Sample	L	a*	b*	Chroma
A	68.28±0.015[a]	7.98±0.012[b]	18.27±0.015[a]	63.74±0.012[b]
B	71.26±0.015[d]	6.57±0.01[a]	16.25±0.015[b]	71.56±0.018[a]
C	74.35±0.021[c]	5.98±0.06[c]	14.38±0.010[c]	74.59±0.008[c]
D	69.35±0.015[b]	6.24±0.08[d]	16.37±0.021[b]	69.63±0.019[d]
E	65.22±0.035[c]	6.06±0.12[c]	18.31±0.015[a]	65.50±0.033[c]

A- Oven drying at 60°C, B- Oven drying at 50°C, C- Oven drying at 40°C, D- Solar drying, E- Sun drying

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Table 5: Engineering properties of dried sample

Sample	Force @ peak (N)	Def @ peak (mm)	Energy @ peak (J)	Force @ break (N)	Def. @break (mm)	Energy @ break (J)	Stress @ peak (N/mm^2)	Strain @ peak (%)	Young Modulus (N/mm^2)
A	313.11±4.91^{b}	8.03±1.01^{b}	1.257±0.04^{d}	92.92±2.01^{bc}	10.82±0.10^{b}	0.473±0.06^{cd}	0.4735±0.02	24.613±0.15	3.24E-2±12E-7
B	355.59±216^{b}	8.19±0.57^{a}	1.440±0.08^{c}	95.07±2.05^{d}	10.98±0.08^{a}	0.521±0.03^{d}	0.5409±0.05	23.515±0.10	3.19E-2±6E-7
C	376.17±6.81^{d}	8.43±0.43^{d}	1.575±0.02^{b}	98.57±1.77^{c}	11.10±0.09^{c}	0.541±0.01^{c}	0.5213±0.03	24.13±10.21	3.15E-2±9E-7
D	361.45±8.21^{c}	8.21±0.19^{c}	1.571±0.05^{ab}	97.42±1.46^{a}	11.13±0.11^{d}	0.547±0.05^{bc}	0.5472±0.01	25.123±0.09	3.14E-2±12E-7
E	380.94±7.92^{a}	8.63±1.31^{a}	1.604±0.09^{a}	99.78±2.40^{b}	11.30±0.15^{c}	0.561±0.02^{a}	0.5614±0.02	24.346±0.17	3.41E-2±15E-7

A- Oven drying at 60°C, B- Oven drying at 50°C, C- Oven drying at 40°C, D- Solar drying, E- Sun drying