

MODELLING THE KINETICS, THERMODYNAMIC AND PHYSICAL PROPERTIES OF COCONUT (*Cocos nucifera* L.) DURING CONVECTIVE DRYING

F. SARPONG*, F. DWUMFOUR, M. T. RASHID & T. ALY

(F. S. & F. D.: Council for Scientific and Industrial Research (CSIR) - Oil Palm Research Institute, Kade, Ghana; M. T. R.: College of Food Science and Engineering, Henan University of Technology, China; T. A.: Regional Center for Food and Feed, Agricultural Research Center, Giza, Egypt).

*Corresponding author's email: fsarpong@csir.org.gh

ABSTRACT

The drying kinetics, thermodynamic properties, and energy consumption of five potential coconut cultivars identified by Ghana's CSIR-Oil Palm Research Institute were studied. Drying was carried out in a convectional dryer using four temperatures (70, 80, 90 and 100°C) and 2.0 m/s air velocity. The asymptotic model was adjudged the best fit model in predicting moisture content based on the highest coefficient of determination (0.9589-0.9998) and lowest residual sum of squares (8.427-252.61), chi-square (0.52671-16.8409) and root mean square error (2.8744-3.4421). Temperature caused between 66.8-96.5% variations in moisture diffusivity. Thermodynamic study revealed endothermic and non-spontaneous reaction in the drying system resulting from enthalpy change and Gibbs free energy change. Meanwhile, a direct relation was established among higher spontaneity and higher temperature. Despite the high drying temperatures used for the experiment, internal cellular composition was not affected as a result of excellent rehydration capacity. In effect, the Vanuatu Tall was adjudged as the best coconut variety based on its lower energy consumption and activation energy, shorter drying time and higher moisture diffusivity.

Keywords: Coconut drying, activation energy, energy consumption, rehydration, asymptotic model.

Introduction

Coconut (*Cocos nucifera* L.), often referred to as “The tree of life” has become an important fruit crop in tropical countries including Ghana. Compositionally, matured coconut fruit consists of water (25%), meat (28%), hard shell (12%) and thick husk (35%) (Chakraborty & Mitra, 2008). The coconut meat has several health benefits including; reducing risk of heart diseases (Hajar, 2017), supporting weight loss as a result of high fibers to boost fullness (Howarth et al., 2001), aid

digestion (Hervik & Svihus, 2019), stabilizes blood sugar (Vijayakumar et al., 2018), lower blood pressure (Sacks et al., 1998) and improves immunity (Patil & Benjakul, 2018). Also, research has suggested that coconut diet prevent kidney stones and stone formations (Worcester & Coe, 2010). In recent times, as a result of health consciousness of people globally; intake of fruits has increased tremendously where the consumers focus is geared toward an additive-free diet (Da Silva et al., 2013). Fruit shelf life is reduced to fewer

days when kept without any additives and one of the traditional preservatives practices has been drying (Sarpong et al., 2018).

Drying of fruit basically removes moisture to improve nutritional and organoleptic properties which also extend the shelf-life for several days during storage (Rashid et al., 2019). The convectional drying has been applied most often at the industrial level due to the uniformity, cheap and fast drying time of the approach. However, drying process is very complex method as a result of many complex reactions that occur simultaneously. This complex process can be understood through the control of model parameters which could be used to design, predict and improve the drying process (Sarpong et al., 2019). In recent times, mathematical models have successfully been used in predicting and improving drying systems in both the academia and industry.

Drying of coconut has generated delicious snacks and several food product on the market using methods such as the use of fluidized bed dryer, solar and sun dryers, microwave and oven dryers (Niamnuy & Devahastin, 2005; Valadez-Carmona et al., 2016). The OPRI with the research mandate on coconut, has identified some promising coconut varieties with regard to exportability, tolerance to the devastating Lethal Yellowing Disease (LYD) known locally as Cape St Paul Wilt Disease, among others. Even though several varieties of the fruit have been produced over the years by the Oil Palm Research Institute (OPRI) under the Council for Scientific and Industrial Research (CSIR), kinetic drying evaluation of promising variety for export has not been conducted. Specifically, main objective of this article is to evaluate the drying kinetics, thermodynamics and physical properties of five promising coconut varieties in Ghana. This has become necessary for OPRI because evaluation of

variety of coconut through drying has never been conducted since its inception, making it difficult to recommend appropriate variety for export to the general public, thus this research was conducted.

Experimental

Material preparation and drying

Fifty-kilogram (50 kg) sample each of matured nuts (11-12 months) of five highly promising coconut varieties in Ghana namely, Sri Lanka Green Dwarf crossed Vanuatu Tall (SGD x VTT), Catigan Green Dwarf (CATD), Tacunan Green Dwarf (TAGD), Vanuatu Tall (VTT) and Indonesian Brown Dwarf (IBD) were selected based on the absence of mechanical and physical wounds and fungal growth. Samples were washed, sanitized and afterward rinsed with distilled water. Coconuts were then de-husked, pared and sliced into approximately 3 cm length and 1.0 cm thick using ceramic knife (CK11A/6, Dolphin Series, CREASHARP China) prior to drying. Drying was carried out with convective oven dryer (SLN 75 POL-EKO-APARATURA, Śląski, Poland) on sieve tray tarred to zero before loading samples (447 g) at four temperatures (70°C, 80°C, 90°C and 100°C) and 2.0 m/s air velocity. The drying condition of the system was run for 1 h to ensure steady drying condition before loading. Weight measurement was obtained at 1 h interval until constant weight was obtained.

Modeling of drying kinetics

Drying theory described by Lewis (1921) which is pillared on law of cooling in heat transfer proposed by Newton was used to describe the mass transfer in thin layer drying for agricultural products.

$$MR = \frac{M - M_e}{M_o - M_e} = \exp(-kt) \quad \text{Eq. (1)}$$

Where MR is moisture ratio, M is moisture content at time t, M_o and M_e are initial and equilibrium moisture (assumed as zero) respectively in dry basis (db) and k is drying constant. The experimental data of MR was fitted into 2 thin layer drying models depicted in Eqs. (2 - 3). Origin-Pro 9.2 was used for model regression analysis and good fit of the model was evaluated using coefficient of determination (R^2), residual sum of squares (RSS), chi-square (χ^2) and root mean square error (RMSE).

Modified Parabolic

$$Mr = c + at + bt^2 \quad \text{Eq. (2)}$$

Asymptotic

$$Mr = a - bc \exp(-k) \quad \text{Eq. (3)}$$

Moisture effective diffusion (D_{eff})

Moisture effective diffusion was evaluated based on Fick's second law of diffusion used for describing drying process at the falling rate period in agricultural materials and is depicted in Eq. (4).

$$\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \quad \text{Eq. (4)}$$

D_{eff} (m^2/s) was estimated for slab geometry based on the following assumption of constant (uni-dimensional moisture movement, volume change, constant temperature and negligible external resistance) according to Crank (1975). The equation is of the form:

$$MR = \frac{M-M_e}{M_o-M_e} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp\left[-\frac{(2n-1)^2 \pi^2 D_{eff} t}{4L^2}\right] \quad \text{Eq. (5)}$$

Where D_{eff} is the constant effective diffusivity (m^2/s) L and t represent half the thickness of the coconut slice and the drying time (s) respectively. Only the first term of the Eq. (6) is used for long drying times

$$MR = \frac{M-M_e}{M_o-M_e} = \frac{8}{\pi^2} \exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad \text{Eq. (6)}$$

The slope (k_o) is calculated by plotting $\ln(MR)$ against time

$$k_o = \frac{\pi^2 D_{eff}}{4L^2} \quad \text{Eq. (7)}$$

Thermodynamics properties

Activation energy (E_a) was estimated based on temperature dependency of drying kinetic using the Arrhenius equation shown in Eq. (8)

$$D_{eff} = D_o \exp\left(-\frac{E_a}{R(T+273.15)}\right) \quad \text{Eq. (8)}$$

Where T represent temperature (K), R is universal gas constant (8.314 J/ (mol K)) and D_o is the Arrhenius constant. E_a was measured in kJ/mol. The E_a and rate of constant of drying kinetic were used for the following parameters; the enthalpy change (ΔH), the Gibbs free energy change (ΔG) and entropy change (ΔS) exhibited in Eqs. (9 – 11)

$$\Delta G = R \times T \times \ln\left(\frac{k \times h_p}{T \times K_B}\right) \quad \text{Eq. (9)}$$

$$\Delta H = E_a - RT \quad \text{Eq. (10)}$$

$$\Delta S = \left(\frac{\Delta H - \Delta G}{T}\right) \quad \text{Eq. (11)}$$

Where K_B the Boltzmann is constant (1.3806×10^{-23} J/K) and h_p is the Planck constant (6.6262×10^{-34} J s)

Energy consumption

The energy consumption (total) used for drying coconut varieties under varied temperatures was measured through electric energy meter with 0.01 kWh accuracy. In the case of specific energy consumption which is defined as the required energy to dry 1 kg of coconut was evaluated using Eq. (12).

$$E_s = \frac{E_t}{W_w} \times 1000 \quad \text{Eq. (12)}$$

Where E_s is the specific energy consumption, E_t is the total energy consumption, and W_w is the initial weight of coconut.

Rehydration capacity (RC)

RC was performed at 30°C in distilled water by immersing approach according to (Krokida & Marinos-Kouris, 2003). A glass beaker containing the distilled water with ratio of 1:50 (w/w%) was used where samples (100 g) were immersed to evaluate the RC. Data of RC was collected at 1, 2, 3, 4, 5, 6, and 7 h where after immersing, samples were blotted with tissue paper to remove excess water before weighing with electronic balance (model SL2002N Shijiazhuang Sanli Grain Sorting Machinery Co. Shijiazhuang City, China). The RC was determined using Eq. (13).

$$RC = \frac{W_r}{W_d} \quad \text{Eq. (13)}$$

Where, W_r and W_d are weight after and before rehydration respectively measured in kg

Statistical analysis

Data analyses collection was performed in triplicate and presented as means \pm s.d. through the processing of Origin-Pro 9.2 (Origin Lab Corporation, Northampton, MA, USA). Data comparison in this manuscript was performed with one-way Analysis of variance (ANOVA) at 5% significant level.

Results and discussion

Drying behaviors of coconut varieties under varied temperatures

The changes in mass from initial weight of 447 g was used to study the drying behavior of coconut slices with an initial moisture content

of 48 ± 3.1 % wet basis (w. b.). Observably, an exponential decrease in moisture was noticed in the overall drying behavior as depicted in Fig. 1. The constant period in drying kinetic theory was absent in the drying behavior of coconut but a faster rate of dehydration was spotted in early stages and decreased over time. Most often high free moisture availability and water diffusion principal accounts for initial and falling stages of drying kinetic behaviors respectively (Mghazli et al., 2017; Sarpong et al., 2019).

Clearly, temperature was the determining factors in causing the variation in rate of dehydration accounting for the differences in drying time as shown in Fig. 1. All the varieties achieved constant weight at 10 h for 100°C as the faster drying time whilst 17-17.5 h drying time was observed in 60°C as longest drying time. The effect of temperature is widely known in literature and is attributed to higher driving force by higher temperatures for heat and mass transfer (Doymaz, 2004; Madamba, 2003). Observably, the VTT variety demonstrated higher dehydration rate among the varieties at 100 and 90°C drying temperatures whilst at 80°C, similar dehydration rate was observed for all varieties.

At 70°C, the SGD \times VTT and VTT achieved the fastest drying time of 1020 min and these variations are as a result of loose copra structural composition which determined the permeability of heat of drying air temperatures to speed rate of dehydration (Fernando & Amarasinghe, 2016). This also implies that larger amount of surface moisture was found in VTT variety which often resulted to faster dehydration in agricultural products when compared with bound moisture (Fernando & Amarasinghe, 2016).

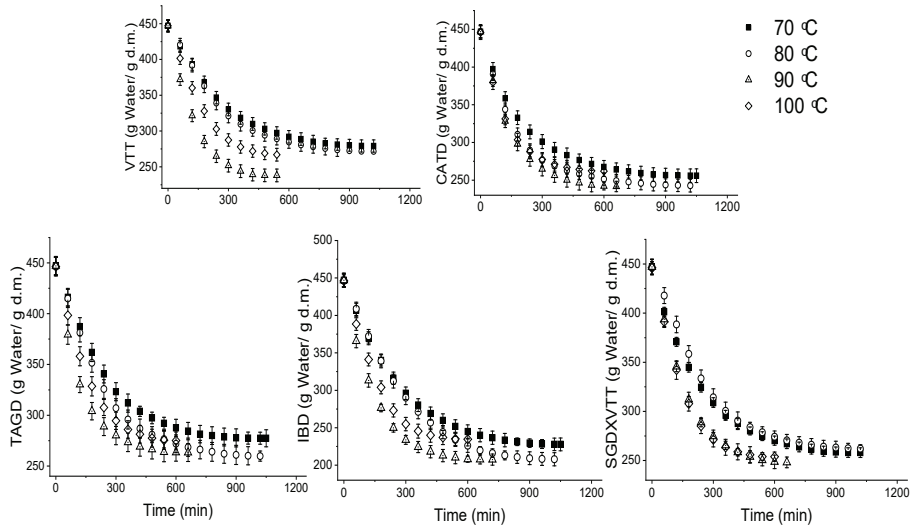


Fig. 1. Drying kinetics coconut slices under varied temperatures for five varieties

Modelling fitting selection

The performance of the tested models was evaluated using four key statistical parameters (R^2 , RMSE, χ^2 and RSS) and the obtained constants are depicted in Table 1. For best model selection, highest R^2 , and lowest RMSE, χ^2 and RSS were used as the criteria and as a result many tested models were rejected in preliminary study. The used models gave R^2 range of 0.9589-0.9998 demonstrating a significant correlation between experimental and predicted moisture content suggesting that the two model can be used in defining the

drying behaviors of the variety of coconut. Asymptotic model was selected based on chosen criteria and was used for the first time as a more accurate model in predicting drying kinetics of coconut varieties due to highest R^2 (0.9589-0.9998) and lowest RMSE (2.8744-3.4421), RSS (8.427-252.61) and χ^2 (0.52671-16.8409) in Table 1. Similarly, this model has been applied in predicting moisture content in coffee bean (Fadai et al., 2018), fish (onJain & Pathare, 2007) and onion slices (Jain & Pathare, 2004)

TABLE 1

The coefficients of the tested models on coconut varieties in Ghana

| Variety | TEMP (°C) | Model Name | Coefficients | | | R ² | RMSE | χ^2 | RSS |
|--------------|--------------|---------------|------------------------|------------------------|-----------|----------------|---------|----------|---------|
| SG- D×VTT | 70 | Parabolic | a=-0.4263 | b=2.6×10 ⁻⁴ | c=423.850 | 0.9708 | 9.9326 | 98.6566 | 1578.50 |
| | | Asymptotic | a=254.92 | b=-191.24 | c=0.99578 | 0.9998 | 2.8744 | 0.52671 | 8.427 |
| | 80 | Parabolic | a=-0.4451 | b=2.7×10 ⁻⁴ | c=435.620 | 0.9791 | 8.7594 | 76.7280 | 1227.64 |
| | | Asymptotic | a=256.32 | b=-198.37 | c=0.99609 | 0.9960 | 2.6754 | 14.7329 | 235.72 |
| | 90 | Parabolic | a=-0.7456 | b=7.2×10 ⁻⁴ | c=434.433 | 0.9820 | 9.5997 | 92.1548 | 829.39 |
| | | Asymptotic | a=241.82 | b=-208.63 | c=0.99406 | 0.9985 | 3.4471 | 7.71304 | 69.41 |
| 100 | Parabolic | a=-0.8150 | b=8.8×10 ⁻⁴ | c=436.118 | 0.9848 | 8.8840 | 78.9267 | 631.41 | |
| | Asymptotic | a=246.21 | b=-204.00 | c=0.99350 | 0.9969 | 2.4460 | 15.9307 | 127.44 | |
| IBD | 70 | Parabolic | a=-0.4965 | b=3.0×10 ⁻⁴ | c=429.271 | 0.9829 | 9.1445 | 83.6234 | 1337.97 |
| | | Asymptotic | a=438.70 | b=-222.92 | c=0.99612 | 0.9979 | 2.7870 | 8.92130 | 142.74 |
| | 80 | Parabolic | a=-0.5635 | b=3.4×10 ⁻⁴ | c=436.166 | 0.9925 | 6.8830 | 47.3757 | 710.63 |
| | | Asymptotic | a=203.59 | b=-243.40 | c=0.99605 | 0.9847 | 3.1424 | 85.4987 | 1282.48 |
| | 90 | Parabolic | a=-0.8357 | b=7.8×10 ⁻⁴ | c=438.704 | 0.9619 | 15.837 | 250.812 | 2508.12 |
| | | Asymptotic | a=206.17 | b=-240.82 | c=0.99278 | 0.9985 | 2.8742 | 8.15348 | 81.53 |
| 100 | Parabolic | a=-0.8860 | b=9.3×10 ⁻⁴ | c=438.704 | 0.9922 | 7.0939 | 50.3237 | 402.59 | |
| | Asymptotic | a=232.87 | b=-213.20 | a=0.99209 | 0.9589 | 2.8788 | 212.509 | 1700.07 | |
| TAGD | 70 | Parabolic | a=-0.4024 | b=2.5×10 ⁻⁴ | c=433.190 | 0.9780 | 8.0872 | 65.4033 | 1046.45 |
| | | Asymptotic | a=275.96 | b=-171.03 | c=0.99542 | 0.9896 | 2.6641 | 30.9723 | 495.55 |
| | 80 | Parabolic | a=-0.4602 | b=2.9×10 ⁻⁴ | c=432.806 | 0.9734 | 9.9529 | 99.0604 | 1485.90 |
| | | Asymptotic | a=256.95 | b=-190.0 | c=0.99588 | 0.9954 | 3.4421 | 16.8409 | 252.61 |
| | 90 | Parabolic | a=-0.7008 | b=7.2×10 ⁻⁴ | c=423.161 | 0.9473 | 14.539 | 211.398 | 1902.58 |
| | | Asymptotic | a=262.39 | b=-184.60 | c=0.99195 | 0.9994 | 4.6211 | 2.36261 | 21.26 |
| 100 | Parabolic | a=-0.7014 | b=7.3×10 ⁻⁴ | c=438.208 | 0.9890 | 6.7211 | 45.1739 | 361.39 | |
| | Asymptotic | a=273.115 | b=-173.17 | c=0.99253 | 0.9820 | 2.8742 | 73.8743 | 590.99 | |
| CATD | 70 | Parabolic | a=-0.4243 | b=2.6×10 ⁻⁴ | c=416.867 | 0.9513 | 12.574 | 158.118 | 2529.90 |
| | | Asymptotic | a=255.598 | b=-189.38 | c=0.99519 | 0.9990 | 2.3331 | 3.21237 | 51.39 |
| | 80 | Parabolic | a=-0.4849 | b=3.3×10 ⁻⁴ | c=410.136 | 0.9216 | 17.109 | 292.734 | 4391.02 |
| | | Asymptotic | a=244.253 | b=-204.21 | c=0.99401 | 0.9987 | 3.1125 | 4.85960 | 72.89 |
| | 90 | Parabolic | a=-0.7758 | b=7.8×10 ⁻⁴ | c=427.206 | 0.9674 | 13.029 | 169.768 | 1527.91 |
| | | Asymptotic | a=238.65 | b=-210.22 | c=0.99310 | 0.9992 | 3.4125 | 3.71861 | 33.46 |
| 100 | Parabolic | a=-0.7683 | b=8.5×10 ⁻⁴ | c=427.363 | 0.9634 | 12.663 | 160.353 | 1282.83 | |
| | Asymptotic | a=259.89 | b=-187.10 | c=0.99214 | 0.9995 | 2.8971 | 1.99018 | 15.92 | |

| VTT | | | | | | | | |
|-----|------------|-----------|------------------------|------------|--------|---------|---------|---------|
| 70 | Parabolic | a=-0.3709 | b=2.1×10 ⁻⁴ | c=433.829 | 0.9697 | 9.7266 | 94.6072 | 1513.71 |
| | Asymptotic | a=267.79 | b=-181.92 | c=0.99662 | 0.9903 | 3.1150 | 26.9288 | 430.86 |
| 80 | Parabolic | a=-0.4288 | b=2.7×10 ⁻⁴ | c=437.498 | 0.9808 | 8.0746 | 65.2002 | 978.00 |
| | Asymptotic | a=265.962 | b=-187.95 | c=0.99616 | 0.9958 | 2.4552 | 12.3967 | 185.95 |
| 90 | Parabolic | a=-0.9743 | b=0.001 | c=432.658 | 0.9819 | 10.715 | 114.824 | 803.76 |
| | Asymptotic | a=231.02 | b=-217.50 | c=0.99248 | 0.9988 | 3.2254 | 5.76996 | 40.38 |
| 100 | Parabolic | a=-0.7809 | b=8.5×10 ⁻⁴ | c=444.3854 | 0.9969 | 3.91538 | 15.3301 | 107.31 |
| | Asymptotic | a=251.64 | b=-199.36 | c=0.99466 | 0.9955 | 3.5540 | 17.4215 | 121.95 |

Moisture effective diffusivity (D_{eff})

Many mass transfer in a drying system often occur simultaneously, however may be dominated or governed by one in a complex reaction (Anabel et al., 2018). In describing the driving force in drying system, effective diffusivity (D_{eff}) is calculated to estimate rate of water loss and in this case, this ranged from 9.85×10^{-9} to 1.36×10^{-9} (Table 2) which is an indication of moisture movement in liquid state. The variation in D_{eff} is attributed to drying

temperature and structural composition (food matrix) of coconut variety which has direct effect on drying forces to vaporize free and bound water (Anabel et al., 2018; Doymaz & Kocayigit, 2012). The D_{eff} values were similar to coconut effective diffusivity of 1.75×10^{-9} - 3.92×10^{-10} observed by Da Silva et al. (2014). D_{eff} increased with increasing temperature and in this case between 66.8-96.5% increase was observed from 60°C to 100°C drying air temperatures.

TABLE 2

Moisture effective diffusivity and thermodynamic properties of coconut variety in Ghana

| VARIETY | Temp (°C) | Deff (m ² /s) | Ea (kJ/mol) | R ² | ΔH(kJ/mol) | ΔG(kJ/mol) | ΔS(kJ/mol) |
|---------|-----------|--------------------------|-------------|----------------|------------|------------|------------|
| SGD×VTT | 70 | 7.31×10^{-9} | 20.20 | 0.9851 | 17.35 | 199.05 | -529.51 |
| | 80 | 8.24×10^{-9} | | | 17.26 | 204.41 | -529.94 |
| | 90 | 1.02×10^{-8} | | | 17.18 | 209.46 | -529.49 |
| | 100 | 1.22×10^{-8} | | | 17.10 | 214.61 | -529.32 |
| IBD | 70 | 6.43×10^{-9} | 25.16 | 1.000 | 22.31 | 199.41 | -516.12 |
| | 80 | 8.00×10^{-9} | | | 22.22 | 204.50 | -516.15 |
| | 90 | 9.85×10^{-9} | | | 22.14 | 209.58 | -516.15 |
| | 100 | 1.20×10^{-8} | | | 22.06 | 214.65 | -516.13 |
| TAGD | 70 | 7.03×10^{-9} | 22.14 | 0.9886 | 19.29 | 199.16 | -524.18 |
| | 80 | 8.23×10^{-9} | | | 19.20 | 204.42 | -524.46 |
| | 90 | 1.02×10^{-8} | | | 19.12 | 209.46 | -524.14 |
| | 100 | 1.23×10^{-8} | | | 19.04 | 214.57 | -524.01 |

| | | | | | | | |
|------|-----|-----------------------|-------|--------|-------|--------|---------|
| CATD | 70 | 6.93×10^{-9} | 21.60 | 0.9769 | 18.75 | 199.20 | -525.88 |
| | 80 | 9.05×10^{-9} | | | 18.66 | 204.14 | -525.20 |
| | 90 | 1.1×10^{-8} | | | 18.58 | 209.25 | -525.03 |
| | 100 | 1.27×10^{-8} | | | 18.50 | 214.47 | -525.18 |
| VTT | 70 | 6.92×10^{-9} | 18.48 | 0.9974 | 15.63 | 199.21 | -534.98 |
| | 80 | 8.13×10^{-9} | | | 15.54 | 204.45 | -534.93 |
| | 90 | 1.15×10^{-8} | | | 15.46 | 209.12 | -533.28 |
| | 100 | 1.36×10^{-8} | | | 12.58 | 212.98 | -502.19 |

Thermodynamic analysis

Evaluation of activation energy (E_a) was based on Arrhenius equation where the natural logarithm of D_{eff} was plotted against absolute temperature ($1/(T+273.15)$) as depicted in Fig. 2 and the resulting slope represented the E_a . The general concept of E_a is to define the required energy needed to reach active state to initiate reaction (Sarpong *et al.*, 2019). The E_a ranged 18.48-25.16 kJ/mol ($R^2=0.9769-1.000$) for 70-100°C, almost half of 44.7 kJ/mol for 50 –70°C obtained by Da Silva *et al.* (2014). However, the E_a was within 10.7-110 kJ/mol for various agricultural products (Zogzas *et al.*, 1996). This is explained by the concept that increase in thermal agitation speed up moisture self-diffusion. Hence, it is expected that increase temperatures will generally reduce E_a . Food matrix of the coconut variety was responsible for variation of E_a confirming the high dehydration rate in VTT variety as lowest values were observed.

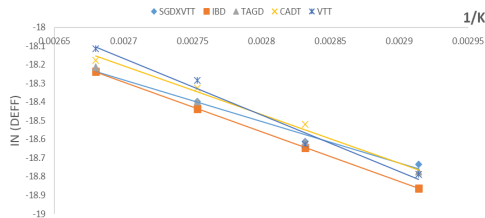


Fig. 2. Demonstrating Arrhenius relationship between the inverse of temperature (Kelvin) and effective diffusivity.

To measure the energy alterations between the activated complex and the reactant, enthalpy change (ΔH) was estimated in the system (Table 2). The ΔH obtained were between 12.58-22.22 kJ/mol. The effect of temperature on the ΔH was insignificant due to the fact ideal gas constant (R) value was very small (Eq. (9)), thus changes observed could be attributed to structural composition of the varieties. The ΔH values also attested to the fact that loose composition variety such as VTT observed smaller energy difference (12.58-15.63 kJ/mol) when compared with the other varieties. The implication in this assertion is that little energy is required to achieve drying of VTT variety when compared with others. Again the positive ΔH values revealed the endothermic reaction during the drying process. Another thermodynamic property worth noting is the spontaneity of reaction also termed as Gibbs free energy change (ΔG) in the drying system. This value ranges from 199.98-214.65 kJ/mol, an indication of non-spontaneous reaction which were affected by both temperature and variety (Sarpong *et al.*, 2019).

A direct relation was established among higher spontaneity and higher temperature and loose structural composition of the variety. The entropy change (ΔS) measured the disorderliness of molecules in the system during drying and the negativity of values obtained seems to suggest a lower structural

freedom in achieving the transition state when compared with reactants.

Energy consumption

The Fig. 3 shows the total energy consumption and specific energy consumption of dried coconut varieties. For total energy consumption, a range of 30.94-54.60 kWh was needed to achieve constant dry weight of coconut. For variety specific, lesser energy was used in VTT in all temperatures when compared with others, confirming the fastest drying time in the drying behaviors of coconut. Beside variety, higher temperatures achieved lesser energy consumption with a significant difference ($p < 0.05$). Other studies have revealed that sample thickness, processing conditions and external environment also play a significant role in energy consumption (Zhao *et al.*, 2018). In similar manner, specific energy consumption increases with decreasing temperature such that 188.66-122.14 kWh/Kg was observed at 70 °C whilst 60.46-69.80 kWh/Kg was achieved at 100 °C.

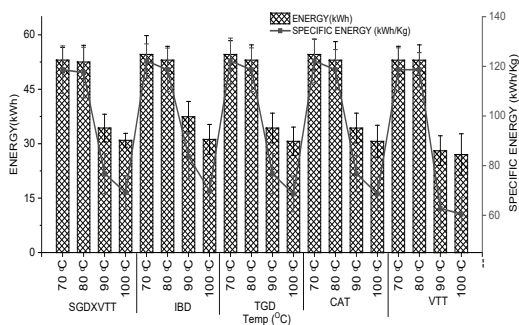


Fig. 3. Energy and specific energy consumption in drying of coconut varieties under varied temperatures.

Rehydration capacity

For quality and injury assessment, rehydration capacity (RC) is one of the important parameters often applied to measure quality and injury caused by drying air temperatures

of dried product (Doymaz & Kocayigit, 2012). Data of RC plotted against time is displayed in Fig. 4. An analyses of the result revealed a higher rate of absorption at the initial stage followed by a gradual lower rate which is typical characteristics of dried product. This is as a result of filling up of capillaries and intercellular space by osmosis principles and with time the available spaces were filled up to slow rate of absorption. Despite the use of high temperatures in the drying experiment, the internal cellular composition of the coconut seems not to be altered and injured as result of excellent rehydrability for the data

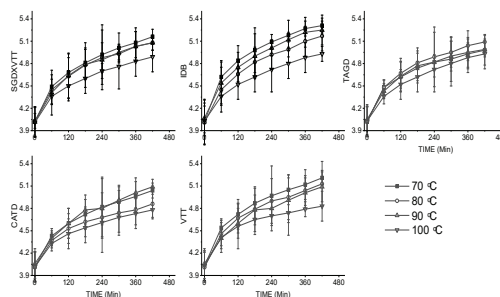


Fig. 4. The Rehydration capacity of dried coconut variety conducted at 30°C.

Conclusion

In this study, five promising coconut varieties identified by the CSIR-Oil Palm Research Institute in Ghana were evaluated in terms of drying kinetic, thermodynamic, energy consumption and some physical properties. Temperature was a factor in causing the variation in rate of dehydration accounting for the difference in drying behaviors. For the first time in coconut drying, the asymptotic model was selected based on highest R^2 , and lowest RMSE, χ^2 and RSS. Between 66.8-96.5% increase in De_{eff} was attributed to variation temperature and food matrix of variety. The thermodynamic analysis revealed that VTT variety was more porous thus has

a highest dehydration rate. Again, the tested ΔH and ΔG revealed endothermic and non-spontaneity reaction in the drying system and were directly affected by both temperature and structural composition of the variety. The internal cellular composition were little altered despite the high drying temperatures as a result of excellent rehydration capacity. In summary, the drying characteristics of the tested variety in terms of energy consumption, thermodynamics and *Deff* follows the order; $IBD < TAGD < CATD < SGD \times VVT < VTT$.

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