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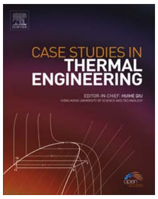

Heat and mass transfer parameters in the drying of cocoyam slice

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ABSTRACT

The paper investigates some heat and mass transfer parameters (HMTPs) of three varieties of cocoyam slice and their vitamin B retention level in convective drying. The varieties include *Colocasia esculenta* (COE) and *xanthosoma sagittiffolium* (white flesh – NX01, red flesh – NX02). The objective is to generate HMTPs for process model development, applied in dryer design. The oven and sun drying procedures were employed where temperatures were maintained between 50 and 70 °C (oven drying) and sun drying, the readings were observed at every one hour. The results obtained show that the mass transfer coefficient for the three varieties lies between 1.01044×10^{-6} and 3.44876×10^{-6} m/s while the heat transfer coefficient ranged from 1.17973 to 3.58284 W/m^2 K. The specific energy consumption for drying was estimated at 14.15, 25.16 and 35.07 kWh/kg for NX02, NX01, and COE respectively, at drying temperature (DT) of 60 °C. However, at DT range between 50 and 70 °C the moisture extraction rate was varied from 0.047 to 0.185 kg/kWh, for NX02, 0.070–0.258 kg/kWh for NX01 and 0.099–1.42 kg/kWh for COE, with vitamin B retention level ranging from 70.13% to 100% at all DTs for the varieties.

1. Introduction

The *Colocasia esculenta* (taro) and *xanthosoma sagittifolium* (tannia) are two main varieties of cocoyam grown in different parts of the world. Cocoyam is grown mainly because of its edible corm, which is rich in vitamin A, B, and C with minerals such as magnesium, calcium, and phosphate [1]. However, to reduce post-harvest losses, producers, dry and process cocoyam into flour for prolong storage and export [2]. Drying is an energy intensive process involving simultaneous heat and mass transfer [3]. Additionally, during this process, there is a movement of heat by convection from the drying medium to the material which permeates the material by conduction. The moisture from the material, in turn, diffuses to the material surface and then evaporates. Consequently, to optimize the drying process, heat and mass parameters of the product must be well understood. This is because the values of the surface heat and mass transfer coefficients in a drying medium are significant in controlling the surface temperature of dried crops. Knowledge of these coefficients can be convenient in providing the basis for the enhanced design of dryers with optimum energy saving.

Moreover, further studies have shown that drying is an integral part of food making and thus all the thermochemical processes involve must likewise be considered as the basic requirements of food processing [4]. The latter comprises moisture behavior, the oxidation of vitamins and minerals, and other enzymatic reactions that alter the original quality and structural matrix [5]. In most cases, to achieve the exact control of the drying processes, models are developed to determine process variables such as drying

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temperature, moisture content, drying time, and product quality index [4].

However, the moisture removal processes during drying, and their relationship with the process variables are expressed regarding the drying characteristics. Consequently, the determination of the drying characteristics is necessary for the development of consistent process models used in the design of dryers for optimum performance [6]. Several studies exist in the literature on drying characteristics (DC) of different crops. For example, the works of [7] presented an all-inclusive review on drying kinetics of numerous crops. Further works in [8] presented the DC of a pretreated unknown variety of cocoyam at a temperature range between 50 and 70 °C using oven and microwave drying techniques. Their inferences indicate the moisture diffusivity (D_m) of the pretreated cocoyam ranged between $5.27\times10^{-8}\leq D_m \leq 2.07\times10^{-6}$ m^2/s while the activation energy (AE) for oven and microwave drying ranged between $37.41\leq$ AE≤61.79 kJ/mol and $38.59\leq$AE ≤41.91 W/g, respectively.

Nonetheless, studies on heat transfer coefficient of *Colocasia esculenta* (taro) a variety of cocoyam is presented in [9] for only deep frying with vitamin C retention capacity. The results of [9] show that vitamin C and β- carotene degraded significantly under heat. Apart from the preceding works of [8,9] on cocoyam drying, studies in the open literature are inadequate in this respect. Similarly, studies on the thermophysical properties of cocoyam and vitamin B retention level in convective drying are not published elsewhere. The research objective is therefore circumscribed to the following, (i) the determination of the heat and mass transfer coefficient and the drying characteristics of three varieties of cocoyam (*Colocasia esculenta*, white flesh and *xanthosoma sagittiffolium,* red flesh) in convective drying procedure and (ii) the determination of the vitamin B retention levels for these three varieties of cocoyam. Since, data in (i) and (ii) have not been adequately provided in the literature regarding the cocoyam varieties, the study contribution in this field is consequently considered worthwhile.

2. Methods

2.1. Determination of heat and mass transfer parameters

In the determination of the heat and mass transfer of food product based on diffusion theory, the following was assumed: (i) the initial moisture content and the drying temperature of the food product is uniform (ii) heat and mass transfer coefficients are constant, homogeneous and isentropic (iii) the effects of interaction between heat and moisture transfer is insignificant [3]. Based on the above assumption several empirical solutions were deduced for several geometric shape coordinates by solving various transient diffusion equations for heat conduction and moisture diffusions, but in most cases, this is simplified by adopting a more general approach [10] as presented in subsequent sections. The experimental setup for the cocoyam slice drying is depicted in Fig. 1.

2.1.1. Convective heat and mass transfer coefficient

The most common method of calculating the heat transfer coefficient of most food materials is to combine the heat and the mass transfer coefficients with the Lewis number (Le) as expressed in [11].

$$\frac{h_c}{h_m \rho \alpha_a}=Le \tag{1}$$

where:
h_c, h_m, α_a and L_e are the heat transfer coefficient, mass transfer coefficient, specific heat capacity and Lewis number respectively. The Lewis number (Le) is obtained in [3].

$$Le = \Phi \ / \ D_m \tag{2}$$

where Φ is the thermal diffusivity and D_m is moisture diffusivity. The surface mass transfer coefficient is expressed in [12] as,

$$h_m=\frac{D_m}{d}(2.0 + 0.522R_e^{0.5}Sc^{0.33}) \tag{3}$$

Where Re and Sc are Reynold and Schemidt number defined in Eqs. (4) and (5)

$$Re= \frac{vd\rho}{\mu} \tag{4}$$

$$Sc = \frac{\mu}{\rho D_m} \tag{5}$$

An infinite series of solution for Fick's second law of diffusion for un- steady state diffusion which can describe the drying rate of cocoyam corm slice was used to deduce the moisture diffusivity (D_m) and expressed in [13]

$$\frac{\partial m}{\partial t}=D_m\frac{\partial^2 m}{\partial r^2} \tag{6}$$

Where r is the radius of the equivalent sphere (m) or thickness of a slab (*l*) and t is the time (s). Assuming uniform initial moisture content (IMC) and a constant D_m all through the sample, the analytical solution of Eq. (6) was given as follows [6].

$$MR = \frac{x_i - x_e}{x_0 - x_e}=\frac{6}{\pi^2}\exp\left[-D_m t\left(\frac{\pi^2}{r^2}\right)\right] \tag{7}$$