Original Research Article

COMPARATIVE ANALYSIS OF THE DRYING PARAMETERS OF *Theobroma cacao*(COCOA BEANS) AND*Musa paradisiacal*(PLANTAIN)

ABSTRACT

In order to prevent microbial spoilage and degradation responses during storage, agricultural products are typically dried to eliminate moisture from them. The removal of moisture is required for the preservation of this substance (drying). Under- or over-drying a product might result in loss through product damage. This work therefore focuses on the drying of two major crops grown by local farmers and agricultural companies;*Musa paradisiaca* and *Theobromacacao*, obtained from a local farmer within Auchi, Edo state. The drying characteristics, including moisture content, moisture loss, and drying rates, were examined experimentally in this studyat the university laboratory and Pax Herbal Clinic & Research Laboratories Ltd. This was obtained with the use of a locally fabricated cross and through circulation dryer for drying and a moisture analyzer to obtain moisture contents while taking into account temperature rangesbetween 40 and 80 °C and time intervalsfrom 5 to 40 minutes. The result of the experiment showed that, the crops' moisture loss and drying rate depend on the time and temperature they are exposed to. The *Musa paradisiaca* crop has more natural moisture than *Theobroma cacao*and hence, it takes a longer time to dry with a rapid moisture loss in the early within 40 to 70 °C and at drying time between 0 and 40 minutes. *Theobroma cacao*dries more rapidlywith a 72% moisture lost at temperatures between 40 and 60 °C. A temperature range of 60 to 70 °C at any drying time would therefore be sufficient to dry *Theobroma cacao* and *Musa paradisiaca*for theirdrying preservation.

*Keywords: Moisture content, Drying rate, Theobroma cacao***,** *Musa paradisiaca, Moisture analyzer.*

INTRODUCTION

1.1 Background of the Study

*Theobroma cacao*also known as cocoa beans from the Sterculiaceae Family [1] are abundant in nations like Cote d'Ivoire, Ghana, Nigeria, Cameroon, Brazil, Equador, Papua New Guinea, Indonesia, and Malaysia because of the wet tropical forest climatic region found in these equatorial countries.Cocoa beans have found use in beverages, pharmaceuticals, cosmetics and toiletries, and the chocolate industry [2]. Africa, where these beans are a major source of livelihood, has a global cocoa capacity of 68% while the remaining 32% is shared almost equally between Southern-America and Asia[3], [4]. Nigeria is the third and fourth largestcocoa producer inAfrica and in the world respectively coming after the world's largest,Ivory Coast (1900 million tons (MT)/year) and Ghana (850 MT)[5].The biological make-up of cocoa beans is extremely complex and changes easily over time depending on the processing method, geographical origin[6].The target industry determines the quality of the beans, storage technologies, and processing conditions [7]. Cocoa is currently being used to treat intestinal infections, diarrhea, and respiratory sicknesses [8].

The primary processing of Cocoa is very time-consuming from the farmer's point of view. It includes harvesting, gathering the ripe fruits at a central location on the farm, fruit opening, removing the beans, fermenting the beans, and drying the beans[9]. Fermentation and drying are particularly important since they are largely responsible for the typical Cocoa flavor precursors which develop later during the roasting of the beans and for the keeping quality of the raw beans.

Plantain is a major group of banana varieties (genus Musa) that are stapled fruits in many tropical areas[10]. Globally, plantains account for about 85 percent of all banana cultivation worldwide. Nearly all edible plantain cultivars are derived from two wild species, M. acuminate and M. balbisiana[11]. These wild species are classified on the basis of the proportion of the genetic constitution contributed by each parental source [11]. With about 32% of global plantain production, West Africa is among the world's largest producers of plantains. Ghana, Nigeria, Côte d'Ivoire, and Guinea are among the region's top plantain-producing nations with Nigeria producing about 2.4 million metric tonnes of the fruit.Itisconsumed as a starchy food by humans either as flour to be used in local and foreign confectionery or as jams and jellies; in chips, etc. Its peel can be used as animal feed[11]. All parts of the banana plant have medicinal applications, the flower in bronchitis and dysentery and on ulcers, cooked flowers are given to diabetics[12]. Its leaves are also useful for lining cooking pots and for wrapping. Improved processes have also made it possible to utilize banana fiber for ropes, table mats, and handbags.

Despite these many uses of *Musa paradisiaca*and*Theobroma cacao* and the huge tonnages each year, there are certain problems such as inaccessibility to production areas, far distances between production areas and customers, inadequate infrastructures for harvesting, carelessness on the part of harvesters and handlers among others which are all factors that lead to high rate of post-harvest losses and raw food wastages[12].

Drying is a simple process of removing excess water or moisture from a product in order to reach the requirement of standard specification moisture content[13]. Drying is important especially to reduce the food product moisture content, as usually these have much higher water content than the one that is suitable for long preservation[14]. Reducing moisture content of food product down to a certain level slows down the action of enzymes, bacteria, yeasts and molds[15]. Thus food can be stored and preserved for long time without spoilage.Drying parameters are key parameters with direct effects on drying and quality of the products [14]. The drying parameters, which can be obtained and calculated for during the drying process are used to determine the efficiency of the drying method used in the drying process. Different drying parameters can be obtained for a particular drying method. Some of the drying parameters include; moisture content, drying rates, diffusion coefficient, chemical acidities and pH, fatty acid content, relative humidity, equilibrium moisture content, drying temperature, moisture ratio [16].

A variety of these drying methods have been investigated separately at various levels in the drying of Cocoa beans[1], [4], [17]–[35] and plantain[36]–[39] with objectives to improve the drying properties and final quality of the products. Some of these drying methods used to obtain quality parameters are open sun, solar, oven, microwave, and freeze drying[5]. Deus *et al*[19] dried cocoa beans at 60 ^{o}C to monitor the activity of antioxidant and the presence of ochratoxin A (a mycotoxin produced by fungi such as Aspergillus ochraceus, Penicilliumverrucosum, etc. and capable of causing kidney cancer). They concluded that there was a reduction in the antioxidant activity, phenolic compound, while ochratoxin A. presence was observed in only one sample after drying. However, they concluded that the traditional method of drying conserved the most antioxidant activity and phenolic compound composition. Castellanos *et al*[18]studied used a combined infrared and convection dryer to study the chemical composition of cocoa beans at 50 ^{o}C, 55 ^{o}C, and 60 ^{o}C. MacManus Chinenye*et al*[28]concluded that the drying process was higherat higher drying temperature, leading to higher drying rates and cost effectiveness, while studying the drying kinetics of *Theobroma cacao L.* under isothermal conditions using a heated batch dryer at 55, 70,and 81^{o}C. Guehi*et al*[21] used solar drying, oven-drying, and mixed-drying methods to check the acidity levels of different degrees of fermented cocoa beans. Hii*et al* [22] improved the quality of Ghanaian, Malaysian, and Indonesian cocoa beans in terms of lower acidity (higher pH) and higher degree of browning using a heat-pump drier and constant step-up air at 30.7–43.6–56.9 ^{o}C. Tardzenyuy*et al*[4] posited that at using a conventional dryer and setting the temperature to 35 °C, time to 96 h, aeration rate to 15 m^3/s, and Space/quantity ratio to 12 m^2/50 kg, the required world standard of 7.0% moisture content of dried cocoa beans can be achieved under the prevailing weather conditions thereby improving the value of dried cocoa beans by $2.8/kg in the local and international market.

Fadimu*et al*[39]analyzed plantain dried with a cabinet dryer, Solar drier, Sun dried, and oven dried while checking the chemical, color, functional and pasting properties, moisture, ash, etc. Their results suggested that any drying method could be used to produce good quality plantain flour. Arinola*et al*[37] suggested that oven and fluidized bed drying provided better alternatives to the traditional natural sun drying of unripe plantain especially in terms of final viscosity, peak viscosity, breakthrough viscosity; chemical and functional properties after testing their viscosities, protein and ash content, pH, energy value, water absorption capacity, oil absorption capacity, and swelling power. In the light of these, this study aims to analyze driedCocoa beans and plantain – two of Nigeria's most abundant food produce usinga locally fabricated two-way dryer. It monitors the moisture content profile using a moisture analyzer and compares the effect of using the same temperature and time ranges to determine their moisture content and drying rate.

MATERIALS AND METHODS

Sample collection and preparation

The Fresh Cocoa pods and matured unripe plantains were obtained from cocoa farmers in Auchi, Edo state Nigeria. The pods were cleansed of the dirt by soaking in flowing water. The beans were removed from the pods and the seeds coat was separated from the cocoa seed. This was used immediately to ensure accurate results. To control browning, the unripe plantains were rinsed with clean water, hand peeled with a stainless kitchen knife, and sliced with a food slicer into a circular shape for even distribution of weight and thickness and wider surface area within 15 minutes. This was then soaked in warm water at 40 ^{o}C for 5 minutes.

Drying procedure

1kgof each of the samples (*Theobroma cacao* and *Musa paradisiaca*) were used for the entire experimental runs.Drying of samples was done with a locally fabricated dryer at temperatures of 40 to 80 °C,and at interval of 5°C using the AOAC (2000) [40] standards. Evaluation of the initial and final moisture content of the two separate samples (*Theobroma cacao* and *Musa paradisiaca*) was obtained using the moisture analyzerXY110MW. Prior to placing the samples in the drying chamber, the locally fabricated dryer was firstly pre-heated to 40° C and ran for 10 minutes to achieve uniform heating and temperatures. The different samples were placed in the moisture analyzer to obtain the initial moisture content at the beginning the drying process. The Cocoa beanswere placed on a clean aluminum tray and placed on the dryer shelf. Further samples of cocoa and plantain, they were dried at the different temperature intervals ranging from 45 to 80 °C using the exact same process. In order to determine the mass of the sample at any point throughout the experiment, the aluminum tray was removed from the drying chamber and weighed on an electronic scale (Mettler Toledo AE 163 Analytical Balance) positioned very close to the dryer.

Drying Rate

The drying rate is the pace at which a substance loses moisture[24], [32]. It is commonly expressed as a percentage of moisture per unit of time. This can be attained at a particular time.

$$\text{Drying rate (DR)} = \frac{(x_i - x_f)}{t_c} \qquad (1)$$

where x_i = initial moisture content
x_f = inal moisture content
t_c = total time elapsed

Moisture Content

The moisture content is the weight of water contained in an object or material[41]. Moisture analyzers is used in this experiment to measure the moisture content. The moisture analyzer weighs a sample, and obtains the moisture content of the sample[42].

Moisture Loss

The moisture loss is the amount of moisture removed in a solid sample [43]. Moisture loss in this experiment was obtained mathematically according to [44]. Using:

$$\text{Moisture loss(ML)} = M_o - M_t \qquad (2)$$

where M_o = initial moisture content
M_t = moisture content measured at time

RESULTS AND DISCUSSION

Moisture content

Figure1 and 2 shows how the moisture contents of cocoa beans and plantains respectively varied with temperature and drying time. As observed for the majority of agricultural products by [45], the moisture levels in every case can be seen to drop as the temperature increased. The continuous decrease in the moisture content with an increase in temperature resulted in the reduced drying time as seen from the negative trend lines at the individual times.

For Cocoa drying, the highest reduction in moisture content occurred between 40 and 60 ℃ for all time trials (between 61 to 82 %moisture content reduction) with the maximum reduction occurring at 60 ℃ for time run of 5 minutes, 40℃ for 10, 15, 25, and 30 minutes of drying, 45 ℃ for 40 minutes of drying This shows that it takes a shorter period with higher temperature for the moisture content of cocoa beans to be reduced effectively. Similar result was also observed in the study of cocoa drying byMujaffar*et al*, Guda*et al*, Hii*et al*, and Waheed& Komolafe[1], [20], [31], [35].

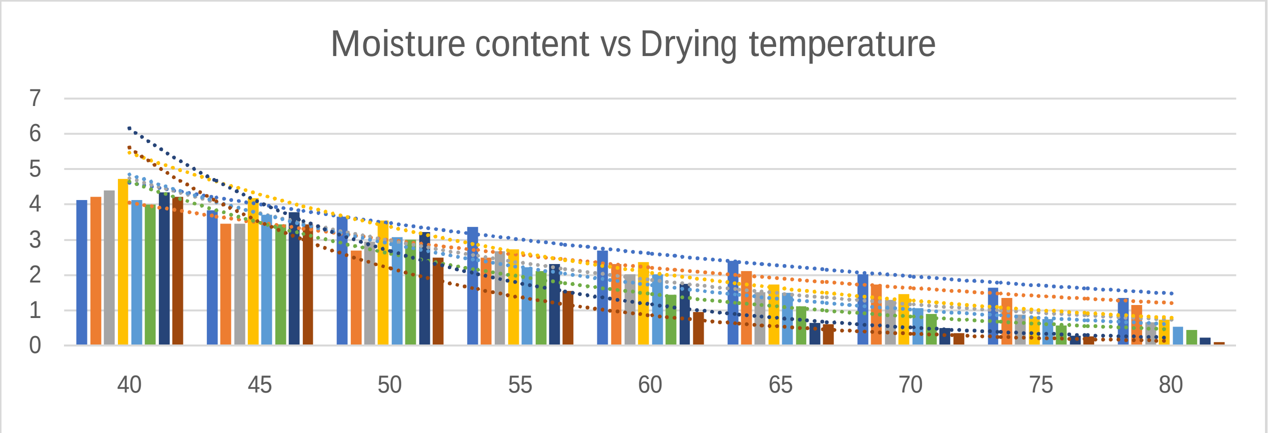


Image 1:Representation of moisture content variation with drying temperature for Cocoa beans

The moisture present in each material reduces with time considering increase in temperature till it attains a near static value[45]. This near static values are as a result of the material approaching moisture equilibrium where there is little or no change in the moisture content of the material even after further subjecting to high temperatures considering time. This phenomenon was observed between 65 and 80 ℃ (36.7% moisture content reduction) and increased drying time.

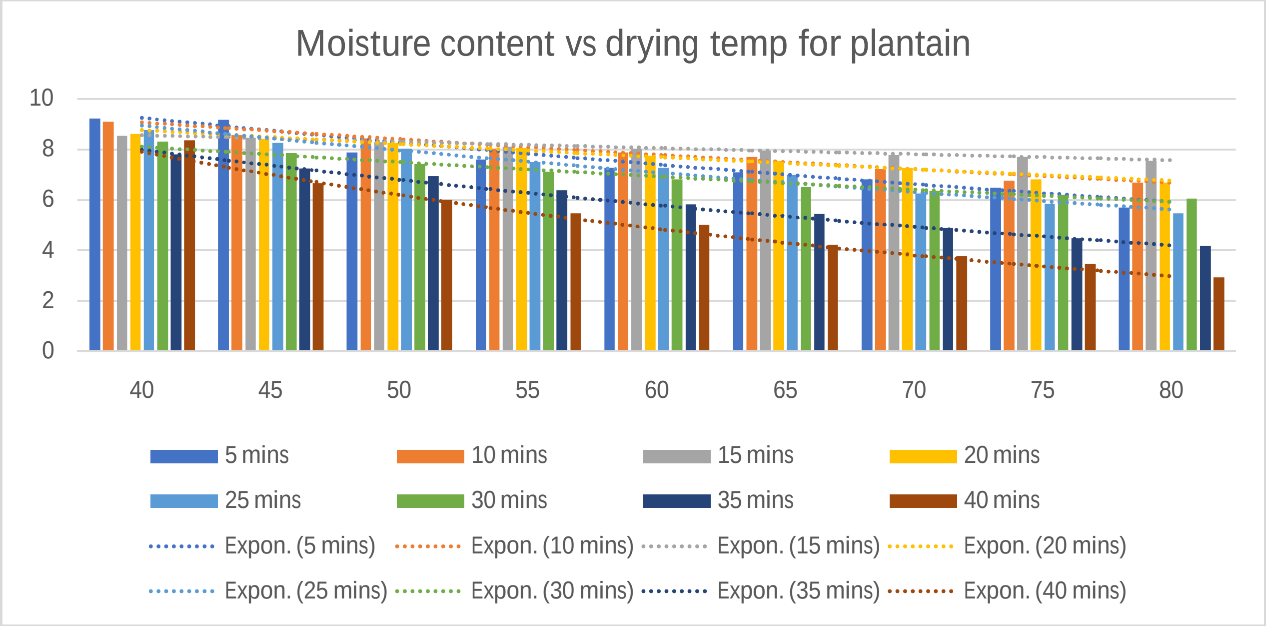


Figure 1: Representation of moisture content variation with drying temperature for Plantain

For the drying of plantain, on the other hand, the highest reduction in moisture content occurred between 40 and 70 ℃[37]for all time trials (73 to 92 % moisture content reduction) with the maximum reduction occurring at 40℃ for time runs of 5 to 35 minutes. However, for 40 minutes of drying of plantain, the maximum reduction occurred at 45 minutes. This is an expected result as the trend line reveals a relatively gentle slope indicating a gradual and progressive overall decrease in moisture content.Ittakes a relativelylonger period with higher temperature for the moisture content of plantainto be reduced effectively. This near static values of plantain was observed between 75 and 80 ℃ with a maximum moisture content reduction of 26.1% at the lowest drying time of 5 minutes[37].

Generally, the moisture content of plantain was far more than those in cocoa seeds (almost double) [37], [39] and from the moisture content reduction plot above, it is evident that cocoa seeds would dry faster than plantain. This experimental data also demonstrates that the primary physical process controlling moisture migration in the drying samples is diffusion[46].

Moisture loss

The moisture loss is the amount of moisture removed in a solid sample [43]. The initial moisture content was obtained by the moisture analyzer using the freshly prepared samples before the drying procedure while the moisture content measured at time was obtained at the various time intervals. Results for the moisture loss was obtained for both samples.

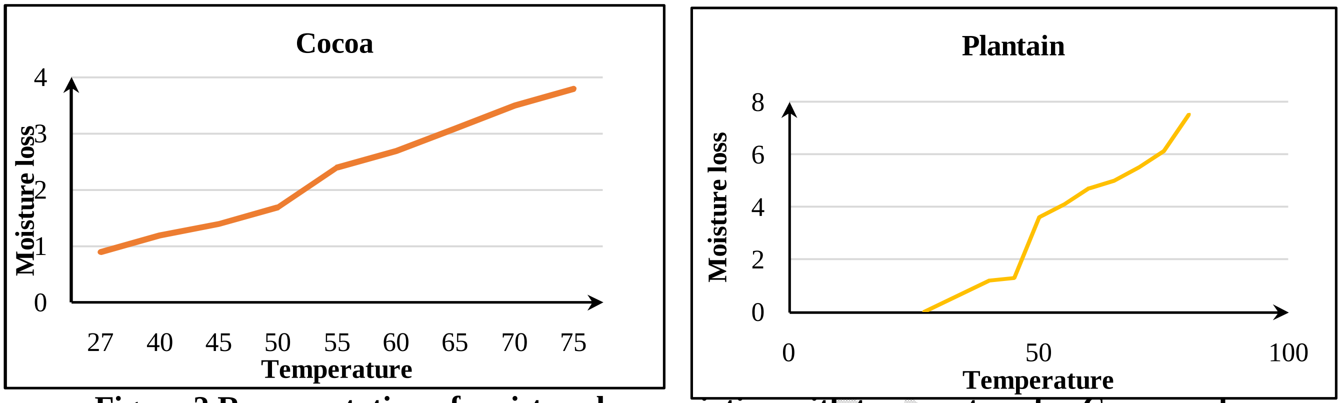


Figure 2 Representation of moisture loss variation with temperature for Cocoa and Plantainat 5minutes

From Figure 2. It was observed that the moisture loss for cocoa and plantain at 5minutes intervalincreased between 50°C and 55°C after which there was continuous increment throughout the remaining temperatures ranging from 60°C and 80°C.

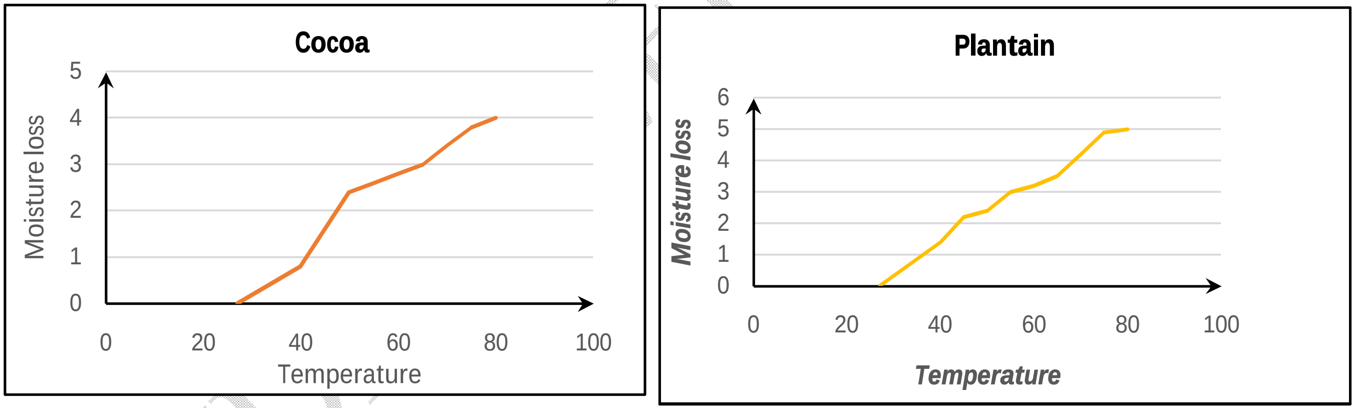
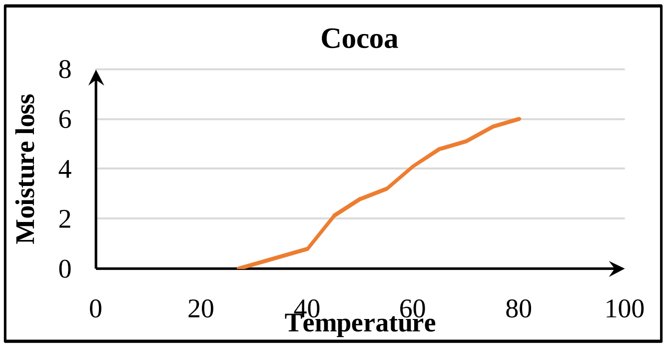


Figure 3 Representation of moisture loss variation with temperature for Cocoaand plantain at 10minutes

From Figure 3. It was observed that the moisture loss for Cocoa and plantain at 10minutes interval increased between 40 and 50°C. It was also observed that the moisture loss from 55°C till approximately 70°C can be negligible.



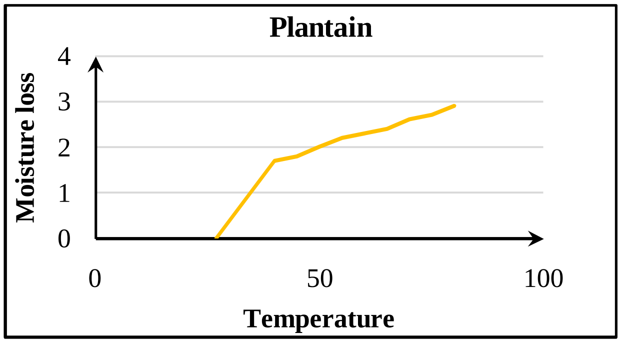


Figure 4 Representation of moisture loss variation with temperature for Cocoa and plantain at 15minutes

From Figure 4. It was observed that the moisture loss for Cocoa and plantain at 15minutes' interval was increasing continuously with increase in temperature throughout the period. But it was seen that there was a negligible change in the moisture loss from 30 to 40℃.

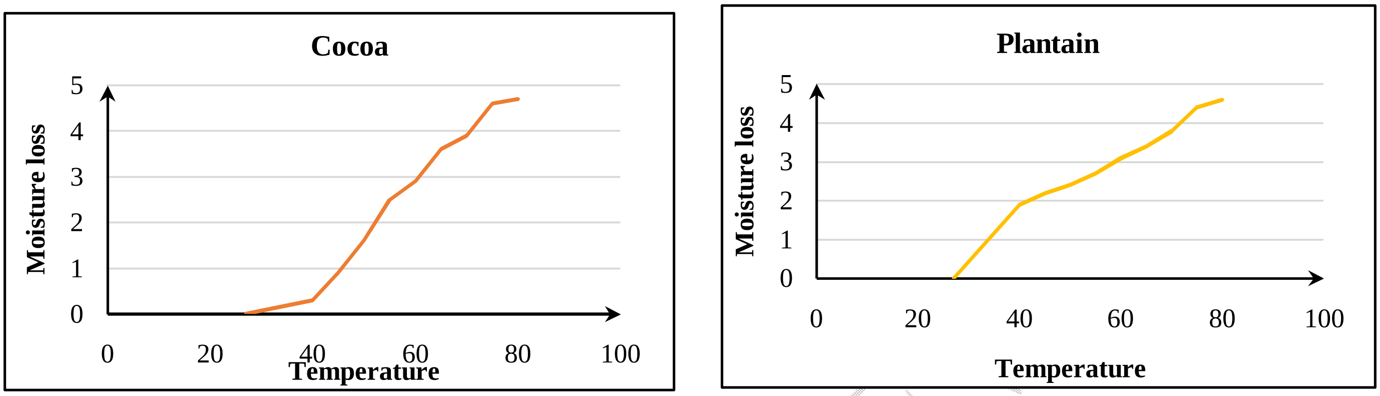


Figure 5 Representation of moisture loss variation with temperature for Cocoa and plantain at 20minutes

From Figure 5. It was observed that the moisture loss for Cocoa and plantain at 20minutes interval was negligible for temperature 30 to 40℃.This was also observed in Figure 4.1.4. The moisture loss over the remaining temperature increased continuously with increase in temperature throughout the period.

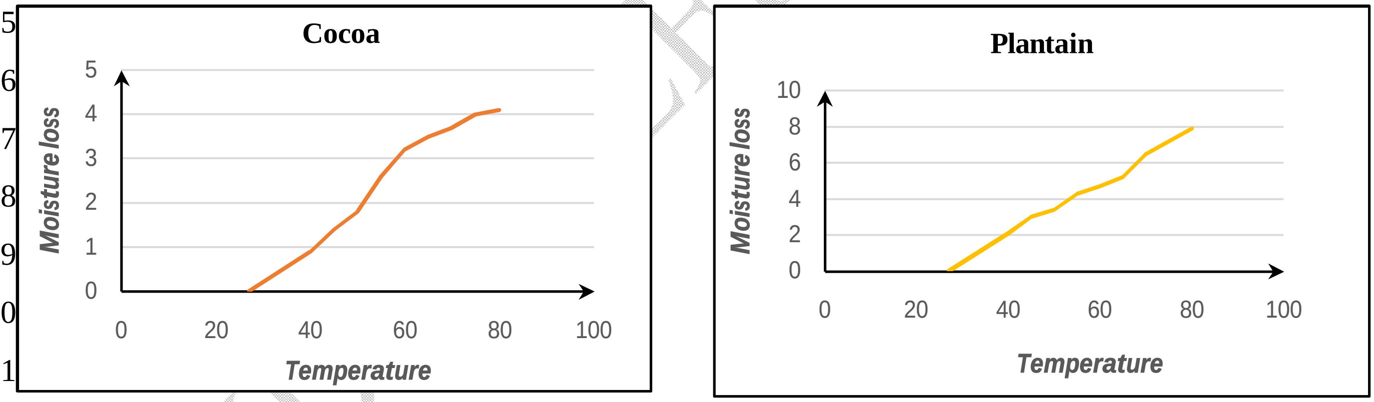


Figure 6 Representation of moisture loss variation with temperature for Cocoa and plantain at 25minutes

From Figure 6. It was observed that the moisture loss for Cocoa and plantain at 25minutes'interval increased noticeably from the first run. It is also observed that at the temperature of 55 to 60℃ little moisture loss occurred here. Moisture loss that occurred between these temperatures was 0.2.

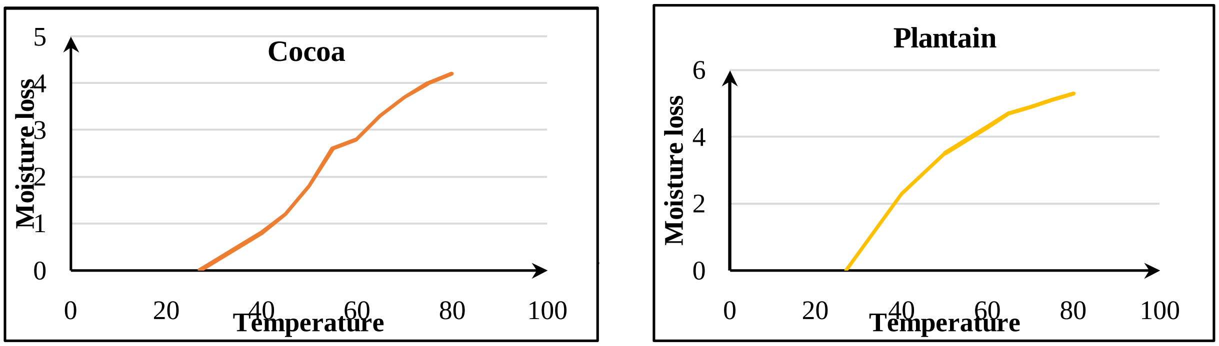


Figure 7 Representation of moisture loss variation with temperature for Cocoa and plantainat 30minutes

From Figure 7. It is observed that the moisture loss for Cocoa and plantain at 30minutes' interval also increased noticeably from the first run. Here the moisture loss at temperature 75 to 80°Cwas negligible having a value of 0.1.

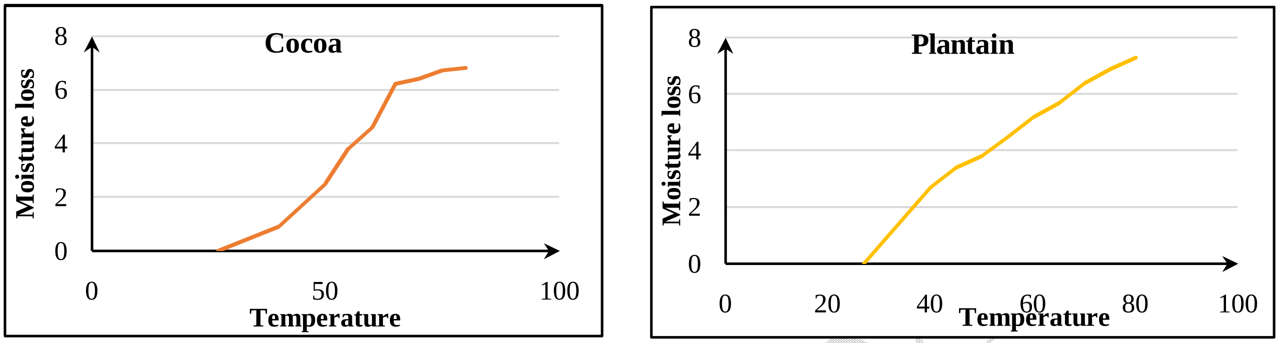
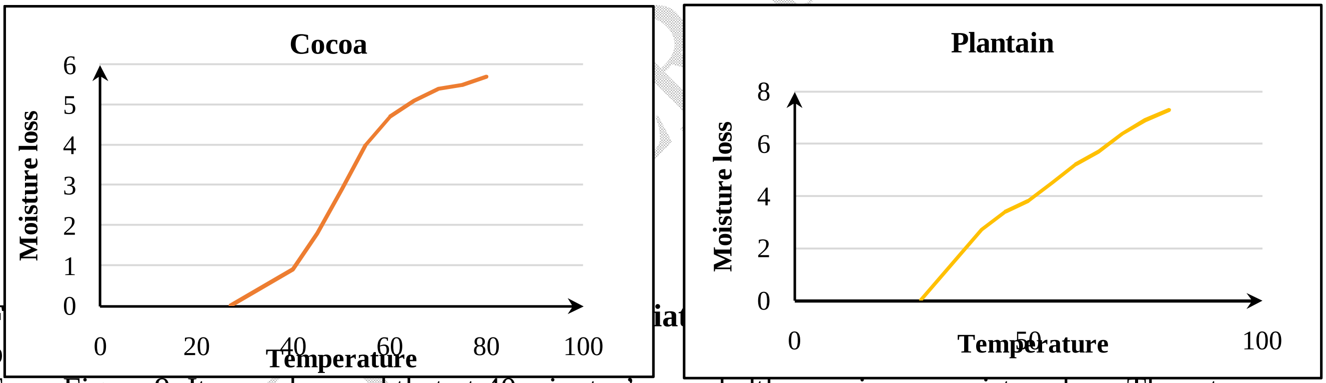


Figure 8 Representation of moisture loss variation with temperature for Cocoa and plantain at 35minutes

From Figure 8. It was observed that the moisture loss for Cocoa and plantain at 35minutes interval is minimal between temperatures 65 and 80°C having a value of 0.6. This implies that at those temperatures, there is no tangible moisture loss.



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From Figure 9. It was observed that at 40 minutes' recordedthe maximum moisture loss. The rate at which the moisture was lost increased directly with an increase in drying time [47]. In general, the figures 1 – 8shows the different rates at which moisture is lost in the cocoa and plantain samples at the different temperatures at constant time of drying. This simply shows the significant change that occurs in the reduction of moisture in the plantain sample as regards to the drying time. This also occurred similarly in the cocoa sample.

4.2. Weight loss

Weight loss was obtained for both samples at the different temperature and time intervals. This was obtained using the moisture analyzer apparatus. A reduction in mass of the materials, cocoa and plantain was also recorded during the drying process as presented in Figure 10 and 11. It was observed that the weight of each sample decreased with an increase in time and temperature [48]. Here at 5 minutes' interval of in-dryer time, and a total time elapsed of 45 minutes at a maximum temperature of 80 °C the weight of the first sample of cocoa was observed to reduce from the initial weight of 3g to 0.85g. This reduction was observed in all the runs for the different samples. The difference in the initial and final weight of the samples was as a result of the reduction in moisture content over time [46].

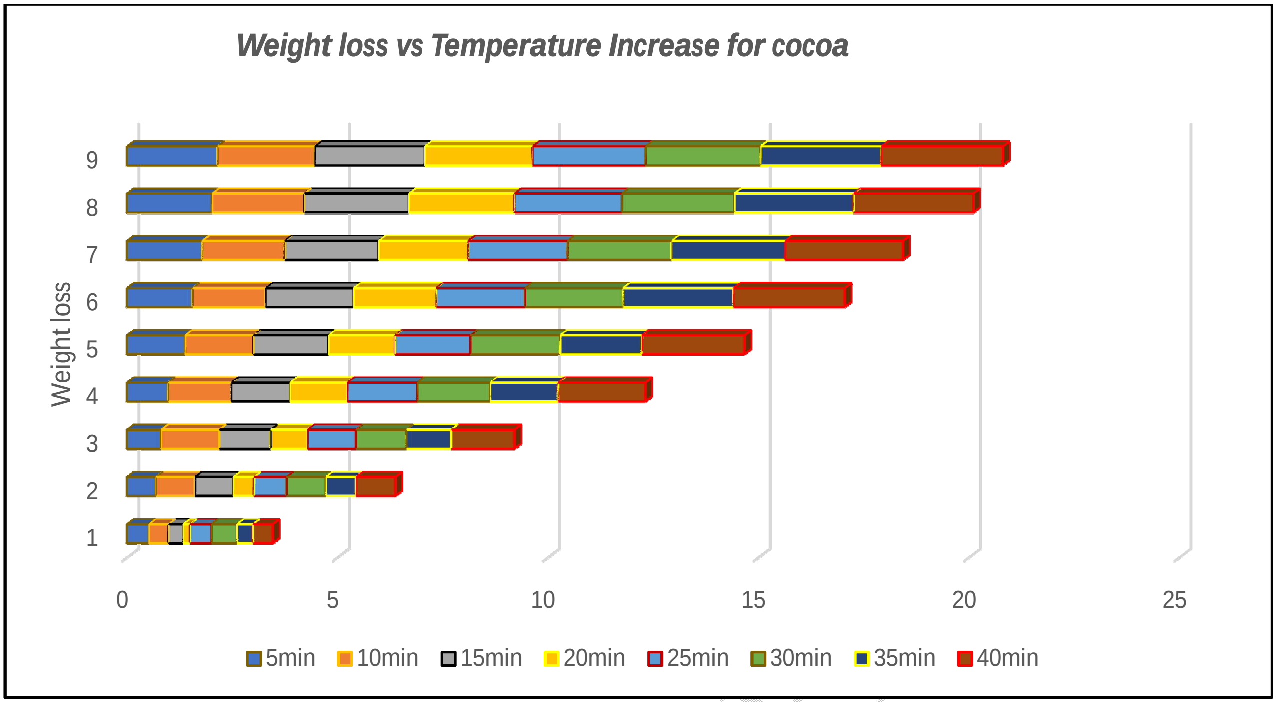

Figure 10 Variation of weight loss with time at the different drying temperatures for Cocoa

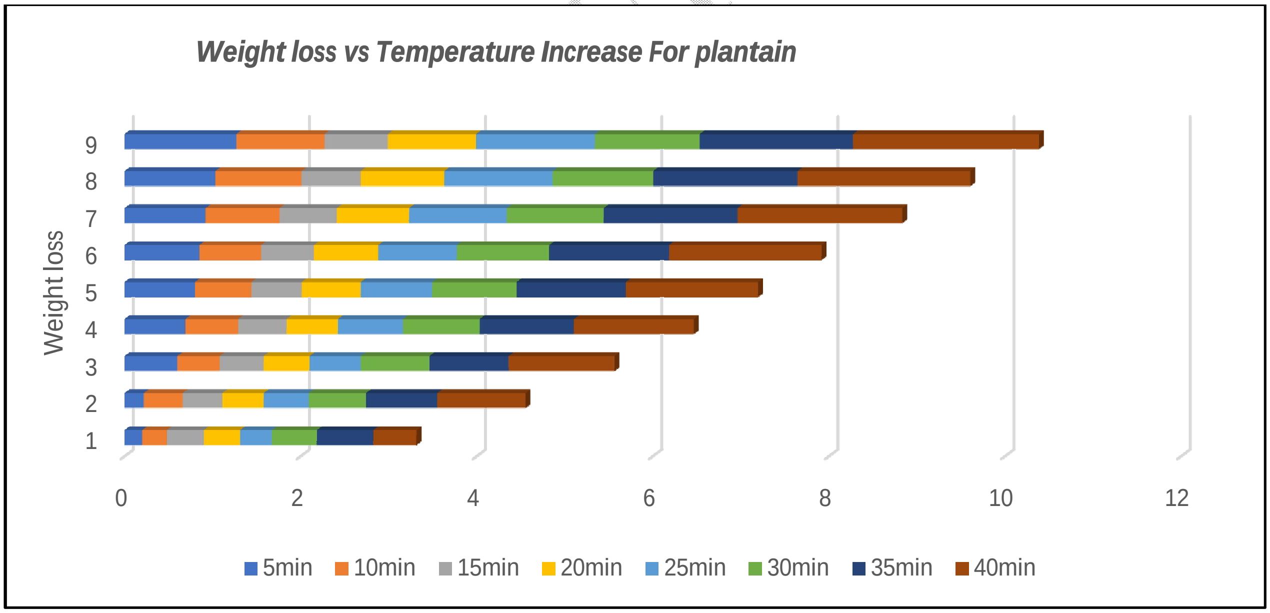

Figure 11showing variation of weight loss with time at the different drying temperatures for plantain

The variations of weight loss with time at the different drying temperatures for the different samples showed that the initial temperature there was minimal weight loss but as the temperature increased over time, there is a steady loss of weight. The largest amount of weight loss was recorded at the highest temperatures.

4.3. Drying Rate

The drying rates for the different samples was obtainedanalytically in this experiment for the different drying time.The drying rate is the pace at which a substance loses moisture [49] is commonly expressed as a percentage of moisture per unit of time.

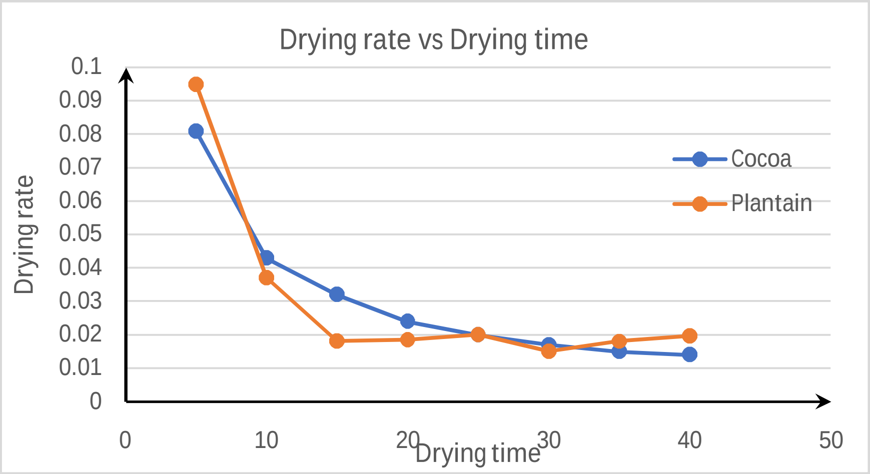

Figure 12 showing Variation of Drying rate with drying for cocoa and plantain

Figure 12 is a plot of the drying rate against the drying time. As expected, the drying time has significant effects on the drying rate of the samples. As the time interval increased from 0 to 40 minutes, the drying rate deceased up till 30 minutes’ interval (70 minutes) when the drying rate became almost constant. At this point, the increase in drying time had little or no effect on the drying rate of both the cocoa and plantain. The highest drying rates occurred rapidly during the early minutes of the drying (between 5 and 15 minutes’ interval for plain) while that of plantain has a smoother slope showing a gradual drying rate gradient from the beginning of the drying time till the 40-minute interval. Similar results were obtained by Komolafe &Waheed[45].

Conclusion

From the analysis of the drying of parameters of *Theobroma cacao* and *Musa paradisiaca*, the following conclusions can be made;

- Drying Cocoa beans and plantain at high air temperature leads to high drying rates, the drying rate and moisture loss at the initial temperature of 40°C is more than double at the final temperature 80 °C.
- The majority (82%) of the moisture loss of cocoa beans occurred between 40 and 60 °C while that of plantain (92%) was more gradual occurring between 40 and 70 °C.
- The drying rate of cocoa with time was more gradual and steady while that of plantain decreased rapidly during the early minutes of drying (between 45 minutes and 55 minutes).
- The maximum decrease in moisture content occurred between 45 minutes of the drying of cocoa while that of plantain

- A temperature ranges of 65 to 70 °C and a drying time of 10 minutes are therefore the optimal conditions for the preservation of residual waste from mass production of (*Theobroma cacao*) and (*Musa paradisiaca*) respectively.

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REFERENCE

[1] C. L. Hii, C. L. Law, and M. Cloke, “Modeling using a new thin layer drying model and product quality of cocoa,” *J. Food Eng.*, vol. 90, no. 2, pp. 191–198, Jan. 2009, doi: 10.1016/j.jfoodeng.2008.06.022.

[2] M. S. Beg, S. Ahmad, K. Jan, and K. Bashir, “Status, supply chain and processing of cocoa-A review,” *Trends Food Sci. Technol.*, vol. 66, pp. 108–116, 2017.

[3] M. S. Beg, S. Ahmad, K. Jan, and K. Bashir, “Status, supply chain and processing of cocoa - A review,” *Trends Food Sci. Technol.*, vol. 66, pp. 108–116, Aug. 2017, doi: 10.1016/j.tifs.2017.06.007.

[4] M. E. Tardzenyuy, Z. Jianguo, T. Akyene, and M. P. Mbuwel, “Improving cocoa beans value chain using a local convection dryer: A case study of Fako division Cameroon.,” *Sci. Afr.*, vol. 8, p. e00343, Jul. 2020, doi: 10.1016/j.sciaf.2020.e00343.

[5] B. F. Dzelagha, N. M. Ngwa, and D. Nde Bup, “A review of cocoa drying technologies and the effect on bean quality parameters,” *Int. J. Food Sci.*, vol. 2020, 2020.

[6] E. Teye, E. Anyidoho, R. Agbemafle, L. K. Sam-Amoah, and C. Elliott, “Cocoa bean and cocoa bean products quality evaluation by NIR spectroscopy and chemometrics: a review,” *Infrared Phys. Technol.*, vol. 104, p. 103127, 2020.

[7] P. Guda, S. Gadhe, and S. Jakkula, “Drying of Cocoa Beans by Using Different Techniques,” vol. 5, no. 5, p. 7, 2017.

[8] M. S. Fowler and F. Coutel, “Cocoa beans: from tree to factory,” *Becketts Ind. Choc. Manuf. Use*, pp. 9–49, 2017.

[9] A. Palakkeel *et al.*, “Development and Performance Evaluation of a Cocoa Bean Sheller cum Winnower,” 2020.

[10] A. F. Al-Daour, M. O. Al-Shawwa, and S. S. Abu-Naser, “Banana classification using deep learning,” *Int. J. Acad. Inf. Syst. Res. IJAISR*, vol. 3, no. 12, 2020.

[11] A. Abiodun-Solanke and K. Falade, “A review of the uses and methods of processing banana and plantain (Musa spp.) into storable food products,” *J. Agric. Res. Dev.*, vol. 9, no. 2, pp. 85–166, 2011.

[12] C. Olumba and C. Onunka, “Banana and plantain in West Africa: Production and marketing,” *Afr. J. Food Agric. Nutr. Dev.*, vol. 20, no. 2, pp. 15474–15489, 2020.

[13] U. E. Inyang, I. O. Oboh, and B. R. Etuk, “Kinetic models for drying techniques—food materials,” *Adv. Chem. Eng. Sci.*, vol. 8, no. 02, p. 27, 2018.

[14] A. Babu, G. Kumaresan, V. A. A. Raj, and R. Velraj, “Review of leaf drying: Mechanism and influencing parameters, drying methods, nutrient preservation, and mathematical models,” *Renew. Sustain. Energy Rev.*, vol. 90, pp. 536–556, 2018.

[15] J. Ma, D.-W. Sun, and H. Pu, “Model improvement for predicting moisture content (MC) in pork longissimus dorsi muscles under diverse processing conditions by hyperspectral imaging,” *J. Food Eng.*, vol. 196, pp. 65–72, 2017.

[16] R. Sivakumar, R. Saravanan, A. E. Perumal, and S. Iniyan, “Fluidized bed drying of some agro products–A review,” *Renew. Sustain. Energy Rev.*, vol. 61, pp. 280–301, 2016.

[17] S. O. Aroyeun, G. O. Adegoke, J. Varga, and J. Teren, “Grading of Fermented and Dried Cocoa Beans Using Fungal Contamination, Ergosterol Index and Ochratoxin a Production,” *Mycobiology*, vol. 37, no. 3, pp. 215–217, Sep. 2009, doi: 10.4489/MYCO.2009.37.3.215.

[18] J. M. Castellanos, C. S. Quintero, and R. Carreno, “Changes on chemical composition of cocoa beans due to combined convection and infrared radiation on a rotary dryer,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 437, p. 012011, Oct. 2018, doi: 10.1088/1757-899X/437/1/012011.

[19] V. L. Deus *et al.*, “Influence of drying methods on cocoa (Theobroma cacao L.): antioxidant activity and presence of ochratoxin A,” *Food Sci. Technol.*, vol. 38, no. suppl 1, pp. 278–285, Dec. 2018, doi: 10.1590/fst.09917.

[20] P. Guda, S. Gadhe, and S. Jakkula, “Drying of Cocoa Beans by Using Different Techniques,” vol. 5, no. 5, p. 7, 2017.

[21] T. S. Guehi, I. B. Zahouli, L. Ban-Koffi, M. A. Fae, and J. G. Nemlin, “Performance of different drying methods and their effects on the chemical quality attributes of raw cocoa material: Performance of different drying methods,” *Int. J. Food Sci. Technol.*, vol. 45, no. 8, pp. 1564–1571, Jul. 2010, doi: 10.1111/j.1365-2621.2010.02302.x.

[22] C. L. Hii, C. L. Law, M. Cloke, and S. Sharif, “Improving Malaysian cocoa quality through the use of dehumidified air under mild drying conditions,” *J. Sci. Food Agric.*, vol. 91, no. 2, pp. 239–246, Jan. 2011, doi: 10.1002/jsfa.4176.

[23] Juliana Puello-Mendez *et al.*, “Comparative study of solar drying of cocoa beans: two methods used in colombian rural areas,” *Chem. Eng. Trans.*, vol. 57, pp. 1711–1716, May 2017, doi: 10.3303/CET1757286.

[24] C. A. Komolafe, M. A. Waheed, S. I. Kuye, B. A. Adewumi, and A. O. Daniel Adejumo, “Thermodynamic analysis of forced convective solar drying of cocoa with black coated sensible thermal storage material,” *Case Stud. Therm. Eng.*, vol. 26, p. 101140, Aug. 2021, doi: 10.1016/j.csite.2021.101140.

[25] J. E. Kongor, M. Hinneh, D. V. de Walle, E. O. Afoakwa, P. Boeckx, and K. Dewettinck, “Factors influencing quality variation in cocoa (Theobroma cacao) bean flavour profile — A review,” *Food Res. Int.*, vol. 82, pp. 44–52, Apr. 2016, doi: 10.1016/j.foodres.2016.01.012.

[26] B. K. Koua, P. M. E. Koffi, and P. Gbaha, “Evolution of shrinkage, real density, porosity, heat and mass transfer coefficients during indirect solar drying of cocoa beans,” *J. Saudi Soc. Agric. Sci.*, vol. 18, no. 1, pp. 72–82, Jan. 2019, doi: 10.1016/j.jssas.2017.01.002.

[27] D. Lasisi, “A Comparative Study of Effects of Drying Methods on Quality of Cocoa Beans,” *Int. J. Eng. Res.*, vol. 3, no. 1, p. 6, 2014.

[28] N. MacManus Chinenye, A. S. Ogunlowo, and O. J. Olukunle, “Cocoa Bean (Theobroma cacao L.)Drying Kinetics,” *Chil. J. Agric. Res.*, vol. 70, no. 4, pp. 633–639, Dec. 2010, doi: 10.4067/S0718-58392010000400014.

[29] Marguerite Belobo Belibi *et al.*, “Comparison of the Performance of Three Cocoa Bean Drying Techniques in Bafia, Southwest Region, Cameroon,” *J. Life Sci.*, vol. 13, no. 2, Feb. 2019, doi: 10.17265/1934-7391/2019.02.004.

[30] R. B. Mbonomo, A. S. Z. Medap, J. K. Brecht, and G. Eyame, “A Study of the Combined Effect of Post-Harvest Fermentation, Turning and Drying of Cocoa (Theobroma Cacao L.) On Beans Quality,” vol. 3, no. 6, p. 5, 2016.

[31] S. Mujaffar, A. Ramroop, and D. Sukha, “Thin layer drying behaviour of fermented cocoa (Theobroma cacao L.) beans,” *Proc. 21th Int. Dry. Symp.*, 2018, doi: 10.4995/IDS2018.2018.7328.

[32] N. R. Nwakuba, P. K. Ejesu, and V. C. Okafor, “A mathematical model for predicting the drying rate of cocoa bean (Theobroma cacao L.) in a hot air dryer,” vol. 19, no. 3, p. 8, 2017.

[33] K. B. Sulaiman and T. A. Yang, “Color Characteristics of Dried Cocoa Using Shallow Box Fermentation Technique,” vol. 9, no. 12, p. 6, 2015.

[34] E. Teye, E. Anyidoho, R. Agbemafle, L. K. Sam-Amoah, and C. Elliott, “Cocoa bean and cocoa bean products quality evaluation by NIR spectroscopy and chemometrics: A review,” *Infrared Phys. Technol.*, vol. 104, p. 103127, Jan. 2020, doi: 10.1016/j.infrared.2019.103127.

[35] M. A. Waheed and C. A. Komolafe, “TEMPERATURES DEPENDENT DRYING KINETICS OF COCOA BEANS VARIETIES IN AIR-VENTILATED OVEN,” *Front. Heat Mass Transf.*, vol. 12, Jan. 2019, doi: 10.5098/hmt.12.8.

[36] M. O. Adegunwa, E. O. Adelekan, A. A. Adebowale, H. A. Bakare, and E. O. Alamu, “Evaluation of nutritional and functional properties of plantain (*Musa paradisiaca* L.) and tigernut (*Cyperus esculentus* L.) flour blends for food formulations,” *Cogent Chem.*, vol. 3, no. 1, p. 1383707, Jan. 2017, doi: 10.1080/23312009.2017.1383707.

[37] S. Arinola, E. Ogunbusola, and S. Adebayo, “Effect of Drying Methods on the Chemical, Pasting and Functional Properties of Unripe Plantain (Musa paradisiaca) Flour,” *Br. J. Appl. Sci. Technol.*, vol. 14, no. 3, pp. 1–7, Jan. 2016, doi: 10.9734/BJAST/2016/22936.

[38] Ebonyi StateUniversity,Abakaliki, Nigeria, C. Olumba, C. Onunka, and University of Nigeria, Nsukka, Enugu State, Nigeria, “Banana and plantain in West Africa: Production and marketing,” *Afr. J. Food Agric. Nutr. Dev.*, vol. 20, no. 02, pp. 15474–15489, Mar. 2020, doi: 10.18697/ajfand.90.18365.

[39] J. G. Fadimu *et al.*, “Effect of drying methods on the chemical composition, colour, functional and pasting properties of plantain (Musa parasidiaca) flour,” *Hrvat. Časopis Za Prehrambenu Tehnol. Biotehnol. Nutr.*, vol. 13, no. 1–2, pp. 38–43, Sep. 2018, doi: 10.31895/hcptbn.13.1-2.2.

[40] G. W. Latimer, *Official methods of analysis of AOAC International*. Gaithersburg, Md.: AOAC International, 2012.

[41] “Lasisi - 2014 - A Comparative Study of Effects of Drying Methods o.pdf.”

[42] S. Z. A. Razvi, I. Kamm, T. Nguyen, J. D. Pellett, and A. Kumar, “Loss on Drying Using Halogen Moisture Analyzer: An Orthogonal Technique for Monitoring Volatile Content for In-Process Control Samples during Pharmaceutical Manufacturing,” *Org. Process Res. Dev.*, vol. 25, no. 2, pp. 300–307, Feb. 2021, doi: 10.1021/acs.oprd.0c00512.

[43] P. Akonor, H. Ofori, N. Dziedzoave, and N. Kortei, “Drying characteristics and physical and nutritional properties of shrimp meat as affected by different traditional drying techniques,” *Int. J. Food Sci.*, vol. 2016, 2016.

[44] C. Kumar and M. Karim, “Microwave-convective drying of food materials: A critical review,” *Crit. Rev. Food Sci. Nutr.*, vol. 59, no. 3, pp. 379–394, 2019.

[45] C. Komolafe and M. Waheed, “Temperatures dependent drying kinetics of cocoa beans varieties in air-ventilated oven,” *Front. Heat Mass Transf. FHMT*, vol. 12, 2018.
[46] B. K. Koua, P. M. E. Koffi, and P. Gbaha, “Evolution of shrinkage, real density, porosity, heat and mass transfer coefficients during indirect solar drying of cocoa beans,” *J. Saudi Soc. Agric. Sci.*, vol. 18, no. 1, pp. 72–82, 2019.
[47] R. Kaur, M. Kumar, O. Gupta, S. Sharma, and S. Kumar, “Drying characteristics of Fenugreek and its computer simulation for automatic operation,” *Int J Curr Microbiol App Sci*, vol. 7, no. 3, pp. 3275–3291, 2018.
[48] P. Guda, S. Gadhe, and S. Jakkula, “Drying of cocoa beans by using different techniques,” *Int. J. Agric. Innov. Res.*, vol. 5, no. 5, pp. 859–865, 2017.
[49] C. A. Komolafe, M. A. Waheed, S. I. Kuye, B. A. Adewumi, and A. O. D. Adejumo, “Thermodynamic analysis of forced convective solar drying of cocoa with black coated sensible thermal storage material,” *Case Stud. Therm. Eng.*, vol. 26, p. 101140, 2021.