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# Banana Drying Kinetics

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## Abstract

Bananas (*Musa acuminata*) are one of the most important tropical fruits consumed worldwide by people of all age groups. Banana fruits are highly perishable, requiring preservation in some forms. Minimal processing, refrigeration and dehydration or drying are among the useful processes used in preserving banana fruits. Drying of banana fruits is used in reducing losses and improving food commercial value. Drying is the process of moisture removal due to simultaneous heat and mass transfer under controlled conditions. Drying as an old method of food preservation is widely embraced because it is simple, easy to operate and cost-effective. Drying also reduces bulkiness of banana through moisture loss which reduces the volume and eases handling and processing operations. This in turn reduces the costs of packaging, handling, storage and transportation. There are different drying techniques with different advantages and shortcomings. Agricultural produce have been dried for ages with natural and artificial methods to preserve them. The drying kinetics of banana is a complex phenomenon, and it is used in predicting the drying behaviour and for optimizing the drying parameters. This chapter assesses the models of drying kinetics in predicting the drying behaviour and in optimizing the drying parameters of banana fruits.

**Keywords:** banana, drying, kinetics, quality, shelf life

## 1. Introduction

Bananas belong to the genus *Musa* [1] and botanical members of berry [2, 3]. Banana chips are a snack produced from sliced dehydrated or fried banana or plantain. Dried bananas are also ground to make banana flour which has several food applications such as production of stiff dough called *amala ogede* in Nigeria and other West African countries. Singh et al. [4] and FAO [5] reported the worldwide production of bananas in 2012 to be 139.2 million tonnes. According to Singh et al. [4], world banana exports are projected to reach almost 17.9 million tonnes in 2011, and India led the world in banana production, producing around 18% of the worldwide crop of 139 million metric tonnes. It was also reported by Singh et al. [4] that more than 85% of global banana production was produced by small-scale farmers, providing an important source of food and income for the small farm households. In 2016, according to FAOSTAT [6], bananas and plantains were 148 million tonnes globally, with India leading and closely followed by China with a combined total (only for bananas) of 28% of global production. The Philippines, Ecuador, Indonesia and Brazil are other major producers accounting for 20% of the global banana and plantain production (**Table 1**).

Country	Banana	Plantain	Total
India	29.1		29.1
China	13.1		13.1
Philippines	5.8	3.1	8.9
Ecuador	6.5	0.6	7.1
Indonesia	7.0		7.0
Brazil	6.8		6.8
Colombia	2.0	3.5	5.5
Cameroon	1.2	4.3	5.5
Uganda	0.6	3.7	4.3
Ghana	0.09	4.0	4.1
Guatemala	3.8	0.3	4.1
World	113.3	35.1	148.4

Source: FAOSTAT [6].

**Table 1.**  
2016 Production in millions of tonnes.

Because bananas are highly perishable, there is a need for dehydration of banana to reduce postharvest losses. Among the useful processes used to preserve banana fruits are minimal processing [7–9], refrigeration [10, 11] and dehydration or drying [12–16]. Drying of banana is a useful method to reduce postharvest losses [17, 18] and to improve commercial value of banana. Drying has become necessary to make them available all year round and at locations where they are not produced. In addition to preservation, the reduced weight and bulk of dehydrated banana products decrease packaging, handling and transportation costs [17, 18]. Drying banana can also lead to quality changes such as physical, sensory, nutritional and microbiological. Omolola et al. [19] reported that drying banana gives rise to low or moderate glycemic index (GI) products with high calorie, vitamin and mineral contents.

Drying is the process of moisture removal due to simultaneous heat and mass transfer under controlled conditions to reduce the bulkiness of the fruits [17, 18, 20–23]. It is one of the oldest methods of preservation and widely applied to banana fruits owing to its simplicity, ease of operation and cost-effectiveness. Besides these advantages, drying decreases the bulk of foods by reducing the volume which reduces packaging, handling and storage and transportation costs as well as ease of handling and processing operations [17, 18, 20–25].

Several researchers have carried out studies on drying of bananas, for example, solar drying [26], drying using vacuum [27], foam mat drying [28] and spray drying [29]. Dried banana is a food stock in ripe [30] or unripe maturation state [31]. The dehydration of banana results also in physical modifications as color change [32], shrinkage and porosity [33, 34] and texture [35, 36]. Based on their findings, important dehydration process variables that have influence on drying process and guarantee the obtainment of dried fruits with good quality have been done. Such parameters are appropriate cultivar, pretreatments and drying conditions [37–40].

A lot of research efforts are geared towards the study of drying kinetic of banana fruits. The drying kinetics are usually used to predict the drying behaviour and for optimization of the drying parameters of various foods [41, 42]. Therefore, the chapter focuses on the existing and emerging drying techniques and drying kinetics of banana.

## 2. Drying techniques

Drying banana is the process of moisture removal due to simultaneous heat and mass transfer under controlled conditions [18, 42, 43]. Drying is the most energy-intensive process in the food industry. Therefore, improving drying processes by reducing energy consumption, increasing efficiency of the drying process and providing high-quality products with minimal increase in economic input have become the goal of modern drying [44–46].

In drying of banana, convective drying in hot air is still the most popular method applied to reduce the moisture content of banana. However, the shortcomings of convective drying in hot air are very long drying period, high-energy consumption, contamination problems, low energy efficiency and high costs, which are not desirable for the food industry [47, 48]. But, the desire to reduce the above problems, as well as to achieve a fast and effective thermal process, led to the use of microwave and dielectric heating methods for banana drying [49, 50]. These drying methods have several advantages such as higher drying rate, shorter drying time, decreased energy consumption and better quality of the dried products when compared with the convective drying in hot air [51–53].

Drying methods are divided into natural and artificial methods of drying. The natural method of drying involves the use of energy from the sun to remove moisture from banana fruits. The major shortcoming of this method is that it depends on weather conditions and is highly inefficient [54]. Artificial method of drying uses mechanical devices to improve drying efficiency of the method [55]; this leads to products of better quality. In addition controlling of various factors involved in the drying process such as temperature, drying air flux and time of drying is also possible. Artificial drying is done with the help of mechanical or electrical equipment which improves efficiency.

### 2.1 Natural drying methods

#### 2.1.1 Solar drying

Sun is as old as the universe itself and is an inexhaustible and free source of energy, utilized for drying of banana since ancient times. Solar drying can be classified into direct and indirect methods of drying.

#### 2.1.2 Direct method

This is a traditional method which involves the sunlight to dry banana. Banana to be dried is left exposed to the sun for several days to achieve the desired moisture content. This is very common in developing countries where fuel is scarcely available to farmers due to high cost; open sun drying is the most popularly used method of drying since it is simple and only requires sunlight [56]. However, the major problems faced by open-air sun drying are insect infestation, dust and dirt contamination, long time for drying, overheating due to direct exposure, quality deterioration and low rate of transmission of heat due to condensation of the evaporated moisture [57]. In order to improve on the sun drying method, a simple form of solar dryer could be used to dry banana slices.

#### 2.1.3 Indirect method

Indirect solar drying involves the use of solar dryer to overcome the problems encountered by the direct method of drying. Different types of indirect solar dryers

are chamber type, chimney type and wind-ventilated dryers. In the indirect method of solar drying, the heat acquired by the system is used to heat the air that flows through the product to be dried.

## 2.2 Artificial drying methods

### 2.2.1 Convective drying

Convective method of drying is used to remove water from banana through heat transfer in modern drying. Hot air is allowed to pass through the banana products in a manner to transfer the heat to the banana, and moisture is removed effectively [58].

Combination of osmotic and convective drying methods have been studied on many fruits and vegetables such as mango [59], mushrooms [60], ginger [61], jackfruit [62], button mushroom [63] and grapes [64], and these methods could be applied to drying of banana.

### 2.2.2 Drying by radiation

It has been discovered and reported that long drying time and high temperature are the factors responsible for the loss of heat-sensitive components of banana in traditional convective hot air drying. Drying by radiation is an alternative method that could be used to overcome the problems encountered in hot air drying. The use of electromagnetic radiation as in the case of microwave radiation is achieved through space by means of electric and magnetic fields. Microwave heating requires lesser amounts of time and temperature to remove moisture from banana slices [65]. One of the problems of microwave heating is due to low availability of water towards the end of the drying process. Radiation through microwave could be combined with other methods of drying such as vacuum drying which is an advantage over other methods [65]. Drying by radiation has been used to dry various agricultural produce including banana [66–68].

### 2.2.3 Freeze-drying

Freeze-drying uses the principles of moisture sublimation to remove from produce. Falade and Igbeka [69] have reported that the non-availability of liquid water during freezing and low temperature results in the production of a superior quality end product and most of the reactions involving the microbes are completely stopped. Freeze-drying method has several advantages over other drying methods in that its products have better rehydration property due to rapid drying and the organoleptic property of the rehydrated banana is almost the same with the fresh product [69]. Other benefits of freeze-drying method are as follows: freeze-dried products have minimum volume reduction, minute chemical change and minimum loss of volatile components [70]. However, freeze-drying is very expensive and uses more energy. Because of longer freeze-drying time, the product may collapse during drying which could lead to loss of aroma [71].

### 2.2.4 Osmotic drying

Osmotic drying involves the use of hypertonic solution; banana slices are placed in a hypertonic solution which causes a difference in concentration gradient and removal of water from banana to the solution. There is also diffusion of the solutes from the solution into the tissue of the banana slices [72]. The mass transfer which occurs during osmosis could be responsible for the change in physical, chemical and



nutritional values, taste and structural properties of the final products [62, 69, 73]. Osmotic active solutes include monosaccharides, disaccharides and salts such as sodium chloride. The major advantage of the process is that it could be conducted at room temperature since energy required for carrying out the procedure is significantly less [74].

### 2.2.5 Hurdle technology

Hurdle technology is a method of ensuring that pathogens in banana fruits can be eliminated or controlled through the use of hurdles. This means the banana fruits will be safe for consumption and their shelf life will be extended. Hurdle technology usually works by combining several approaches thought of as 'hurdles' which the pathogen has to overcome if it is to remain active in banana flour. The right combination of hurdles can ensure that all pathogens are eliminated or rendered harmless in the final products [75].

Leistner [77] defined hurdle technology as a planned application and combination of hurdles which eliminates or reduces the microbial load and makes dried banana safe and stable as well as improves or maintains the organoleptic and nutritional quality and the economic viability of dried banana. The organoleptic quality of the banana products refers to its sensory properties, which includes look, taste, smell and texture.

Several combinations of hurdles are used in banana preservation. Examples of hurdles in a banana fruit system are high temperature during processing; low temperature during storage, increasing the acidity and lowering the water activity or redox potential; or the presence of preservatives. Alasalvar [76] reported that bananas are preserved according to the type of pathogens and how risky they are. The author reinstated that the intensity of the hurdles can be adjusted individually to meet consumer preferences in an economical way, without compromising the safety of the products.

Several hurdles are considered to be important in the preservation of various vegetables and fruits including banana to enhance their stability and shelf life. Shelf-stable grated carrot products are developed using hurdle technology.

## 2.3 Drying kinetics and modelling

The *drying kinetics* is used to describe the combined macroscopic and microscopic mechanisms of heat and mass transfer during *drying*, and it is affected by *drying* conditions, types of *dryer* and characteristics of materials to be *dried*. Studying drying kinetics is a means to choose appropriate drying methods and to control the processes of drying. It is also important for engineering and process optimization. Drying kinetics is used to show removal of moisture from products, and it has to do with process variables, and hence, a better understanding of drying rate will help in developing a drying rate model [78]. There are three drying models, namely, theoretical, semi-theoretical and empirical according to Khazae and Daneshmandi [79]. Theoretical models dealt with internal resistance in transfer of moisture, while semi-theoretical and empirical models worked on external resistance in the transfer of moisture between air and products [80]. Empirical model's main shortcoming is that it does not consider the basics of drying process but explains only the drying curve for drying conditions but not the processes that occur during drying [81]. Examples of semi-theoretical models are the Lewis model, Henderson and Pabis model, Logarithmic model, Page model, etc.

The theoretical model that is commonly used in drying rate is Fick's second law of diffusion. Theoretical models have been found to be inadequate, tend to generate

erroneous results and are complex for practical applications. Therefore, in food drying semi-theoretical models have been developed as a better model to fit the drying data of banana fruits to be dried [82]. In the case of the Henderson and Pabis model, it was first used for model drying of corn. But due to inaccuracy and high degree of temperature difference between kernel and air, the model could not be fitted during the first 1 or 2 h of drying banana [83]. The Lewis model is a special case of the Henderson and Pabis model [84]. However, the model has been found to be inaccurate because it overestimates the first period and underestimates the last period of drying. But, semi-theoretical models have been found to be the simplified general series solutions of Fick's second law (**Table 2**).

2.3.1 Effect of air temperature and air velocity on drying kinetics

In drying kinetics, air temperature is one of the major factors influencing the drying kinetics during dehydration. Krokida et al. [83] reported that the drying constant, equilibrium moisture content and moisture diffusivity increase as the temperature increases. Tzempelikos et al. [85] in their experiment on the time of drying banana fruits found that the drying was influenced by the air temperatures and air velocities used for drying. They discovered that drying time was reduced by 30% with increase in the air velocity at a temperature of 60°C, while 54% reduction in drying time was observed when temperature was increased from 40 to 60°C at an air velocity of 2 m/s.

2.3.2 Effect of shape on drying kinetics

Borges et al. [86] studied the influence of shape on the drying kinetics of banana. They reported that the shape of produce has positive influence drying kinetics and that the drying rate was significantly higher with disk-shaped Dagua banana as compared to the cylindrical shaped banana. They also reported that shape of produce has positive influence on drying temperature of Parta banana and observed that the effect of blanching in Parta banana could be seen when dried at 40°C as compared to shape; the air velocity and air temperature were found to have a more profound effect on the drying time. They also observed that the drying square slices were lower than the cylindrical samples.

Models for drying	Formulas	Reference
Two term	$MR = a \exp(-k_0 t) + b \exp(-k_1 t)$	[81]
Simplified Fick's diffusion equation	$MR = a \exp[-c(t/L^2)]$	[82]
Henderson and Pabis	$MR = a \exp(-kt)$	[83]
Modified page II	$MR = \exp(\exp(-c(t/L^2)n))$	[60]
Lewis model	$MR = \exp(-kt)$	[85]
Simplified Fick's diffusion	$MR = a \exp(-c(t/L^2))$	[60]
Page model	$MR = \exp(-kt^n)$	[62]
Modified page	$MR = \exp[-(kt)^n]$	[63]

Key terms: T—drying time (s); a, b, c, g, n—dimensionless constants for drying; k, k<sub>b</sub>, k<sub>o</sub>—drying velocity constants; exp—exponential; MR—moisture ratio; L—thickness of the material; R—correlation coefficient.

**Table 2.**  
Mathematical models used in banana drying kinetics.

### 2.3.3 Effect of pretreatment

Pretreatment is done in banana slices before drying has been found to reduce the drying time, to improve taste and structure, to preserve flavour and to maintain the nutrition of banana. Pretreatment reduces the initial moisture content and modifies the tissues of the banana fruits which help to accelerate the drying rate [87].

Common pretreatments applied to fruits prior to drying operation include blanching, lemon juice, ascorbic acid, sulfuring, honey dip, salt solution and osmotic pretreatment, ethylolate, NaOH, olive oil, skin puncturing and  $K_2CO_3$  [88–91, 92]. Studies have shown that pretreating with an acidic solution or sodium metabisulfite dip also enhances the destruction of potentially harmful bacteria during drying, including *Escherichia coli* O157:H7, *Salmonella* spp. and *Listeria monocytogenes* [92].

### 2.3.4 Effect of relative humidity

Relative humidity has serious effect on drying rate and drying kinetic of banana fruits. Misha et al. [93] worked on the effect of humidity and temperature in the drying kinetics. They used drying temperature (45, 50 and 55°C) and relative humidity (10, 20 and 30%) variations at an air velocity of 1.0 m/s. They found that two-term model described the drying kinetics more accurately and then the rest of the models used in the experiment. They also found that the drying time was reduced as the temperature increased at constant air humidity. They observed that relative humidity of the air had an insignificant effect on the drying curve; this was attributed to the initial moisture content of the sample.

### 2.3.5 Mass transfer parameters

Drying process is used to prolong the storage or shelf life of banana products without changing the quality, structure and chemical properties. This is critically needed for quality of banana products and availability. The efficient and effective drying process could be obtained through an effective use of time, energy and cost [94]. This could also be seen in through speed and timely removal of moisture during the drying process. It has been established that moisture removal depends on the drying method and this will affect the technique of moisture movement towards evaporation for the drying process. Moisture movement is also effective moisture diffusivity and activation energy dependence [94].

### 2.3.6 Effective moisture diffusivity

Effective moisture diffusivity is defined as movement of moisture in banana products and is drying rate related [94, 95]. The difference between effective moisture diffusivity and drying rate is that effective moisture diffusivity is related to moisture velocity within the material, while the drying rate is the moisture vapourizing rate to air and depends directly on the pressure gradient that exists between material and the air due to a temperature gradient [94]. Effective moisture diffusivity is the parameter used to determine the drying rate of banana products and an indicator to determine an appropriate drying method that could be used to extend the banana product shelf life.

Also, according to Omolola et al. [87], effective moisture diffusivity is said to be a function of material moisture content and temperature, as well as of the material



structure [91]. Omolola et al. [87] in their work reported that the values of moisture diffusivities increased with increasing oven temperature. Similar observation was made by Aghbashlo et al. [95], Caglar et al. [96] and Doymaz and Ismail [97]. Omolola et al. [87] also reported that the disparities in moisture diffusivity values obtained in their study and the values reported for banana by Marinos-Kouris and Maroulis [98] and Thuwapanichayanan et al. [99] may be attributed to the effect of variety, geographical location, composition and tissue characteristics of the bananas.

### 2.3.7 Activation energy

Activation energy is energy needed to sever the moisture particles bonding for moisture movement in banana drying [94, 95]. Relationship between effective moisture diffusivity and activation energy is associated with drying characteristics and the effect of drying conditions on effective moisture diffusivity and activation energy of products [95, 100–102]. According to Xiao et al. [103], the activation energy, for a typical drying operation, ranges from 12.7 to 110 kJ/mol. Doymaz [104] reported the activation energy for drying banana slices to be 32.65 kJ/mol.

In determining activation energy, the Arrhenius equation is used in a modified form to illustrate the relationship between moisture diffusivity, mass transfer coefficient and ratio of drying process output power density to sample amount or the temperature for the calculation of the activation energy on the drying process [105, 106].

$$D_m = D_0 \exp\left(\frac{E_{ad}m_0}{P}\right) \quad (1)$$

$$H_{m-av} = h_0 \exp\left(\frac{-E_m m_0}{P}\right) \quad (2)$$

## 2.4 Quality aspects of dehydrated banana flour

### 2.4.1 Rehydration ratio

Rehydration of banana slices depends on processing conditions, sample preparation, sample composition and extent of the structural and chemical disruption induced by drying [107]. Singh and Pandey [107] reported that the duration and severity of the drying process with the speed and degree of rehydration reflect faster and complete rehydration with decreased drying time. They opined that a minimization of shrinkage and the presence of well-defined intercellular voids show to promote increased rehydrating rate. Dried banana slices could be rehydrated at 25°C for 2 h by being immersed in 60 mL of distilled water. The rehydration ratio is described by:

$$Rr = \frac{m_1 - m_d}{m_1} \quad (3)$$

### 2.4.2 Color measurement

Color is a vital quality characteristic in dehydrated banana to nearly every consumer. It serves as an indicator of the intrinsic good qualities [108]. The relationship of color with consumer acceptability is common and inevitable [108]. It has been reported that drying operation changes the surface characteristics of foods and hence alters their reflectivity and color [109]. The color of food products is a very

important quality parameter. L (lightness), a (redness) and b (yellowness) color values of the fresh and dehydrated banana slices can be measured using a spectral photometer or a colorimeter before and after drying.

Total color change and hue angle could be calculated as follows:

$$\Delta E = \left( (L_d^* - L_f^*)^2 + (a_d^* - a_f^*)^2 + (b_d^* - b_f^*)^2 \right)^{1/2} \quad (4)$$

$$H = \tan^{-1} (b/a) \quad (5)$$

#### 2.4.3 Bulk density and shrinkage

The bulk density is the ratio of the mass of banana slices to its total volume, and it can be determined by filling the slices in a cylinder of known volume and then weighing with a balance [110].

$$\rho_b = m/V \quad (6)$$

Shrinkage is an important change in the physical state of the product during drying which affects the quality of the final material, producing large alterations in its volume. Shrinkage can be expressed as ratio between the initial volume and the volume at a certain time after the moisture loss processes. Ramos et al. [111] reported shrinkage is the reduction of the product size which is a result of the reduction of its cellular dimensions of the product due to loss of moisture. According to Aguilera [112], shrinkage which occurs as a result agricultural produce drying is due to viscoelastic matrix contraction into the space previously filled by the water removed from the cells during dehydration.

Shrinkage of bulk banana slices could be represented by:

$$Sh = (V^d/V_0) \quad (7)$$

#### 2.4.4 Consumer perceptions/concerns and expectations about innovative and emerging banana processing technologies

Consumers around the world are better informed and educated as well as more demanding in their purchase preferences for quality health-promoting banana products. The banana industry has continued to search for innovative and novel technologies to provide safe, quality and stable banana products for human consumption. However, nonthermal processing technologies offer unprecedented opportunities and challenges for the banana industry to produce and market safe, high-quality health-promoting banana products. The research and development of nonthermal processing technologies for banana processing will provide an excellent balance between safety and minimal processing, as well as provide a balance between economic and quality requirements of the banana products [113]. Nonthermal banana processing is believed to be a new alternative to thermal banana processing.

Currently, there are many nonthermal banana processing and preservation opportunities and challenges that need further research by the food industry. The advocates of nonthermal technologies rest their argument not only in the inactivation of microorganisms and enzymes but also in improving yield and development of foods with novel quality and nutritional characteristics [114, 116, 118]. Nonthermal processing could be effectively combined with thermal processing

to provide improved banana safety and quality. Nonthermal processing has been found to facilitate the development of innovative banana products. Nonthermal technologies have been used to decontaminate, pasteurize and produce commercial sterilization of some banana products with good quality and excellent nutrient retention. The most important priority for future food science research will be the demand by consumers for technologies to meet consumer expectations with optimum-quality safe-processed banana. Zhang et al. [113] listed priorities and factors to consider when conducting research into novel nonthermal and thermal technologies for quality safe banana products as target microorganisms to provide safety, target enzymes to extend quality shelf life, maximization of potential synergistic effects, alteration of quality attributes, engineering aspects, reliability and economics of technologies and consumer perception of banana products from these technologies. They are of the opinion that the new technologies 'to process foods should be driven at maximizing safety, quality, convenience, costs, and consumer wellness' [115, 117–119].

#### *2.4.5 Glass transition on shrinkage in convective drying*

Several methods are employed for the preservation of banana products; drying is one of them. Drying is a heat and mass transfer process which removes moisture and thereby reduces the water activity of the banana products through vapourization or sublimation, which minimize enzymatic and microbiological reactions within the banana products. Several researchers have worked on drying and drying rate of different food materials. The drying rate has been found to depend on factors that influence the transfer mechanisms, such as the vapour pressure of the material and of the drying air, the temperature and air velocity, water diffusion in the material, the thickness and surface exposed for drying [120, 121].

Shrinkage of dried banana products is an important change in the physical state of the product during drying which affects the quality of the final material, producing large alterations in its volume. This phenomenon during drying is affected by glass transition. According to Roos [121], glass transition temperature ( $T_g$ ) is the temperature at which an amorphous system changes from the glassy to the rubbery state. According to him in the glassy state, molecular mobility is extremely slow, due to the high viscosity of the matrix. Thus, the  $T_g$  can be taken as a reference parameter to characterize properties, quality, stability and safety of dried banana products [122].

Mayor and Sereno [123] and Bhandari and Howes [124] found that at most drying conditions, a significant amount of the dried product remains in the amorphous state, mainly due to insufficient time for crystallization to occur at the given drying condition. They observed that at rubbery state, shrinkage almost entirely compensates for moisture loss and changes in material volume are equal to the volume of removed water. However, it was observed that in food systems, shrinkage is rarely negligible, and it is advisable to take it into account when predicting moisture content profiles in the material undergoing dehydration [125–127].

#### *2.4.6 Optimization of drying conditions of bananas in tray dryer using response surface methodology*

Drying of banana products involves mass transfer phenomenon. Volume reduction or shrinkage occurs simultaneously during drying process, and it is an undesirable phenomenon in dried products. In general, reduction in volume is due to moisture transfer from dried banana products. This could be as a result of heat transfer into banana slices and mass transfer from the inside to the surroundings thereby causing unfavourable changes in dimensions and shape of the dried products [128, 129].

Response surface methodology (RSM) is a collection of statistical and mathematical techniques that has been successfully used for developing, improving and optimizing processes [129]. RSM enables a reduction in the number of experimental trials needed to evaluate multiple parameters and their interactions, thus requiring less time and labour. RSM has been widely applied for optimizing processes in the food industry [128–130]. It is used for product quality improvement in the drying process and has been widely used in new product development, as well as in the improvement of existing product design [130, 131]. There are already a number of studies on RSM applications in optimization of food processes that include optimization of banana production, processing parameter optimization for obtaining dry banana with reduced cooking time [132–134].

### **3. Conclusions**

This chapter showed that moisture content of banana fruits at harvest time is too high for storage and needs to be reduced. Drying characteristics, quality and mass transfer parameters for drying of banana slices were explained, and the process was discussed. It has been found that higher values of effective moisture diffusivity will accelerate moisture velocity within banana slices to achieve removal of moisture from produce for equilibrium moisture content at specific relative humidity. This will help in designing an effective drying method that will save time and energy consumption as well as cost to get good quality products. It was explained that Suzuki's model could be used to explain shrinkage during hot air drying process for banana slices. Shrinkage is a phenomenon and a significant alteration to be considered on quality of dried banana in food engineering applications. The use of this approach will be valuable to select proper drying conditions in order to obtain good quality dried banana products.

### **Conflict of interest**

There is no any conflict of interest.

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