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Mathematical Modelling of Thin-Layer Drying of Pale-Fleshed, White-Skinned Spherical Sweet Potato (Ipomoea Batatas)

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ABSTRACT

In this study, the mathematical modelling of hot air convective drying of (Ipomoea batatas L.) pale-fleshed, white-skinned spherical sweet potato (a variety newly introduced and grown in Burkina Faso), were investigated at 50°C, 60°C, 70°C and 80°C air temperatures. Sweet potato samples were prepared at 2 and 3 cm diameter and dried using a convective oven dryer. For this purpose, forty-three (43) mathematical models were used to estimate the drying coefficients following nonlinear regression method to find the best fit of the moisture ratio models obtained from experimental database on the following parameters: coefficient of determination (R^2), Sum of Squared Errors (SSE), and Root Mean Square Error (RMSE). Drying data analysed were obtained in the period of falling drying rate. The modelling results obtained showed that almost all models had R^2 greater than 0.90 which shows their competitive fit to the drying data of sweet potato spherical samples. Based on statistical parameters results obtained, sweet potato spherical samples can be best dried at 70°C with 3 cm diameters. The Haghi and Angiz-I model was the best fit for predicting the moisture ratio of sweet potato spherical samples dried in hot-air oven dryer based on average values from statistical analysis (R^2 =0.999587, RMSE =0.004375 and SSE= 0.002175).

Keywords: Mathematical modelling, drying kinetics, drying model.

1. Introduction

Food security is one of the major global challenges facing the world today. An estimated 795 million people are food insecure and undernourished (Mc Carthy et al., 2018). One of the factors leading to food insecurity is the loss of food and agricultural products due to their deterioration throughout the food and agricultural chain and/or during the post-production period. A major method to enhance food security is to reduce losses due to post-harvest spoilage of these agricultural products. To improve shelf life and reduce spoilage of agricultural products, drying is the most commonly used method (Onwude et al., 2018). Drying is a unitary operation that aims at eliminating water from a product and consequently reducing its water activity. Drying food products has many advantages, such as inhibiting microorganism growth and spoilage reactions by reducing water activity, as well as reducing transportation and storage costs due to reduction in weight and volume of products (Castro et al., 2018).

Convective drying is the process of removing water with air via simultaneous transfer of heat, mass, and momentum. The necessary heat is transmitted to the food by a flow of hot air. Energy is transferred to the surface of the product by convection and then transferred to the interior of the product by diffusion or convection, depending on the biological configuration of the wet product (Compaore et al., 2017). This heat flow causes an increase in the product temperature and the evaporation of surface water. Moisture is transferred from the surface of the product to the air by convection in the form of water vapor and from the interior of the product by diffusion, convection, or capillarity (Xie et al., 2023). The drying rate and properties of the dried product depend on the external conditions of the drying process such as air temperature, humidity, velocity, and direction of air flow (Aranha et al., 2024). Additionally, the drying rate depends on internal conditions of the moist product, such as geometry, thickness, shape, and structure of the product (Ayonga et al., 2023). The complexity of the structure and composition of wet foods, the variety of transport phenomena, and the biological diversity make food drying a challenge. For these reasons, mathematical modelling and simulation constitute an appropriate tool to deal with the complexity of food drying. This also helps to achieve the appropriate operational conditions through optimization. Mathematical modelling of food drying involves using mathematical equations to predict the behaviour of the drying operation (Castro et al., 2018). Many mathematical models of drying processes are used to design new drying systems, to improve existing drying systems, or even to control the drying process. Among these many mathematical models proposed to describe the drying process, thin-layer drying models have been widely used. The term "thin layer" is applied to a single kernel freely suspended in the drying air or one layer of grain kernels. It is also applied to a poly-layer of many grain thicknesses if the temperature and the relative humidity of the drying air can be considered for the purpose of the drying process calculations, as being in the same thermodynamic state at any time of drying (Ertekin & Firat, 2017). Thin-layer models can be classified as theoretical, semi-theoretical and empirical (Doymaz et al., 2023). Recently, many researchers have focused on the mathematical modelling and experimental drying processes of various tuberous roots such as sweet potato.

Sweet potato (Ipomoea batatas) is a tuber crop with immense potential because it produces more edible energy on marginal lands than any other major food crop. In addition to this useful property, it can resist unwanted abiotic and biotic stresses and does not require intensive care. Therefore, it plays an important role in the economy of poor households, where it constitutes a major source of subsistence and is considered a 'relief crop against famine'. In addition to this important function, its cultivation has immense industrial value for starch extraction and animal feed production. For all these reasons, sweet potatoes offer great possibilities for improving food and nutritional security in developing and underdeveloped countries where most farms belong to vulnerable population categories (Amagloh et al., 2021). Sweet potatoes are important tubers rich in fibre, starch, vitamins, minerals and bioactive compounds. They contain essential carotenoid, phytochemical, anticancer, and antimicrobial properties useful for human and animal health. Raw sweet potato or in its processed form can be consumed by humans as a staple food, snack, or baked product. However, sweet potato is susceptible to microbial activities that can lead to degradation and spoilage due to its high moisture content. Additionally, sweet potatoes are seasonal and cannot maintain an optimal quality level for a long period after harvest. Thus, it is often used shortly after harvest or preserved using the hot air convection drying method (Onwude et al., 2019). In the literature, several drying techniques and processes have been applied in various varieties of sweet potatoes to improve the fundamental understanding of sweet potato drying and allow it to meet a wide range of needs in different regions of the world.

To do this, modelling convective drying of 3-9 mm thick slices of thin layer sweet potato of Kumara variety was examined under conditions of 50-70 ° C air temperatures, 10 -15% air relative humidity, and 0.5-3 m/s air velocities. The modified Page model described convective drying of these thin-layer sweet potato slices to a moisture content of 10% on a dry basis (Diamante & Munro, 1993). A drying test on sweet potato *variety "Kotobuki"* was carried out under drying conditions of 40-75°C air temperature to calculate its drying characteristics. The diameter of the sample was 52.0 mm and its thickness was between 3.9 and 4.1 mm. In this test, three types of drying periods, constant rate drying period, first falling rate drying period and second falling rate drying period, were found on its drying characteristic curves. Furthermore, drying constants during the two decreasing rate drying periods exhibited an Arrhenius-type model dependent on samples temperature (Moreno-Perez et al., 1996). Panigrahi *et al.* (1996) dried two varieties of high-protein sweet potatoes (*white-fleshed Bosbok variety and orange-fleshed Carmel variety*) at air temperatures of 40, 60 and 80°C, to examine effects on their nutritional value. Sweet potato variety and air temperature were important factors influencing the nutritional value of sweet potato tubers. Mass diffusion during hot air drying of cubes (cube with an edge length of 1 cm) of osmotically concentrated sweet potatoes (orange fleshed, jumbo, moist-type) sweet potatoes was evaluated at a 55°C air temperature. The cubes were concentrated in 50 and 60% (kg_{solid}/kg_{water}) corn syrup solutions at 25°C for 2 and 5 h. Effective mass diffusivity values were not significantly different during the convective drying of unconcentrated sweet potatoes and osmotically concentrated sweet potatoes (Biswal et al., 1997). Tan *et al.* (2001) studied thin layer drying of sweet potato chips and pressed grated sweet potatoes of the *"Beni azuma" variety*. The drying conditions were as follows: air temperature set at 33°C, 51°C and 70°C; air flow rates between 0.084 and 0.145 $m^3/(s{\cdot}m^2)$ and an absolute humidity of 1.003×10^{-2} $kg_{water}/kg_{dry\ air}$. The drying rates of the pressed grates were higher than those of the chips. The modified Page model described thin-layer convective drying of pressed chips and grated forms. Falade and Solademi (2010) modelled the air drying (at 50-80 °C air temperatures) of blanched sweet potato slices of thickness (5, 10, and 15 mm). The rectangular slices of sweet potatoes had the same 50 mm length and 20 mm width. These slices were blanched with water at 100°C for 2 min. The Page and Modified Page models best describe the drying curves (i.e., moisture content ratio vs. drying time profiles) of these blanched sweet potato slices. The effective diffusion coefficient increased with increasing samples thickness and air temperatures. Convective air drying was carried out in a cabinet dryer at five levels of air temperatures (50, 60, 70, 80 and 90 ◦C), five levels of air speeds (1.5, 2 .5, 3.5, 4.5 and 5.5 m/s) and three edge lengths (5, 8 and 12 mm) of sweet potato cubes. Sweet potato cubes were blanched in hot water at 80°C for 25 min before convective drying. Two mathematical models available in the literature were fitted to the experimental data. The page model gave better prediction than the first-order kinetics of Henderson and Pabis model and satisfactorily described drying characteristics of sweet potato cubes (Singh & Pandey, 2012). Dinrifo (2012) dried a century-old Nigerian variety of (4±0.02) mm thick sweet potato slices using a hot air dryer operating at air temperatures of 50, 60, 70 and 80 ° C with air velocity fixed at 1.25 m /s. The sweet potatoes were cut perpendicular to the main axis of the whole tuber. Sweet potato slices were blanched by different methods: some samples were blanched in hot water at 100°C for 2 min. Other samples were immersed in sodium metabisulfite of 0.01% concentration at 100 ° C for 2 min. The experimental drying data were fitted to four well-known drying models: Modified Page, Wang and Singh, Two Term Exponential and Approximation of Diffusion. Among the four models considered, the modified Page model was found to best describe the drying kinetics of the sweet potato blanched slices. Banishment methods made it easier to induce the water release process during sample drying. Convective drying experiments of a local variety of Chinese sweet potato slices with 0.002 - 0.004 m thicknesses, were carried out in a drying tunnel at drying temperatures ranging from 60 to 80°C, in increments of 5°C, at an air velocity ranging from 0.423 to 1.120 m/s and a 10–15% relative humidities. The sweet potatoes slices had same rectangular dimensions of 30 mm length and 20 mm width. The levels of temperature, velocity, and thickness influenced the drying process significantly

(Zhu & Jiang, 2014). The Logarithmic model was found to fit well to the experimental drying data for this temperature range and that the Wang and Singh model was found to be the most satisfactory for these velocity and thickness ranges (Zhu & Jiang, 2014). The thin layer drying of slices of Nigerian variety sweet potato of three thickness (5 mm, 10 mm, and 5 mm) was carried out at air temperatures of 50, 60 and 80 ° C, at 2.5 m s^{-1} and 10% relative humidity in a hot air tray dryer. The rectangular dimensions of slices were 20 mm length and 20 mm width. Sweet potato slices were blanched by holding them in distilled water at 45°C for 30 minutes before the drying process. The blanched slices dried more quickly than the unbleached slices. Page's model fitted well the drying data of all sweet potato samples at 50, 60 and 80 °C air temperatures (Olawale & Omole, 2012). Sweet potato slices of 1.5 mm thickness were dried in a forced convection tray dryer to model their drying kinetics at high air speed. Experiments were carried out at air temperatures of 40, 50 and 60 °C with air velocities of 14.336, 15.724 and 17.212 m/s. Page and modified Page models and the Henderson and diffusion models could be assumed to represent the drying behaviour of sweet potato chips in a forced convection tray-type dryer within these experimental conditions (Lijauco, 2017) . To model the hot air thin layer drying process of sweet potato slices, air temperature levels (50, 60, 70 and 90°C) were used on slices of 0.3, 0.4, 0.6 and 0.8 cm thick. The ambient air condition was taken as 20°C and 50% relative humidity. The Hii et al. model was found to describe well the drying of sweet potato slices when fitted to experimental drying data (Fan et al., 2015). Hot air drying of biofortified sweet potato chips of 4.6 cm in in length, 4.0 cm in in width and 0.2 cm thickness was carried out in an air circulating oven at air temperatures of 45, 55, 65 and 75°C with an air velocity of 1.0 m/s. The Wang and Singh model was found to represent the convective drying of biofortified sweet potato pulp using Akaike and Schwarz's Bayesian (Souza et al., 2019). Sweet potato strips with rectangular dimensions (5 mm x 5 mm x 30 mm) were dried at air temperatures of 40°C, 50°C, 60˚C until a constant weight was obtained. Before drying, sweet potato strips were soaked in 2% potassium metabisulfite solution at 50˚C for 15 minutes to preserve sample freshness and to help prevent active growth of microorganisms. The Laplace Transform Model; the Non-Linear Decomposition Model and the Page Model are the three mathematical models that were compared to determine what is the best fit for the drying of the sweet potato. Based on data gathered, the Page model fitted best from the other two models to obtain the desired moisture content of 10% (Obregon et al., 2020). Drying experiments on 5 mm thick sweet potato slices were carried out at drying temperatures varying from 50 to 70°C, with an increase of 10°C, at a constant air velocity of 2. 0 m/s. The relative humidity of the air and the equilibrium water content were, respectively, between 4% and 25% and between 0.012 and 0.020 $kg_{water}/kg_{dry\ matter}$. Sweet potato slices had rectangular dimensions of 30 mm in length and 48 mm in width. These slices were blanched in hot water at 70°C for 2 min before drying. The Logarithmic model showed the best fit to the drying data of blanched sweet potatoes (Doymaz, 2011b). Thao and Noomhorm (2011) dried 1 cm thick starch layers of a sweet potato variety with white skin and yellow-red flesh from *Kratai cultivar* in an air tray dryer, an infrared dryer and a fluidized bed dryer. The starch samples obtained by filtration were dried at temperatures of 45, 55 and 65 °C for all drying methods. The starch obtained was passed through a 1.6 mm diameter sieve to create particles of uniform size before drying. Thin-layer models were used for describing the drying behaviour of sweet potato starches under the three dryers. The Midilli et al. model was found to explain the drying behaviour of starch well for all drying conditions to reach a final moisture content of 10 % The drying conditions only slightly affected the colour, gel texture, swelling power, solubility and pasting properties of starches.

However, there is little information on the convective drying process of white-skinned and pale-fleshed sweet potatoes in the literature. Due to the need to increase the use of sweet potato flour for human consumption, reduce annual losses of harvested sweet potato tubers, and increase the availability of flour products throughout the year, it is possible to model the convective drying of sweet potato spheres of this variety. The main objectives of this study were to determine the air-drying kinetics, to do an inventory of thin-layer drying models being in literature and to determine a drying model capable of describing the drying data of white-skinned and pale-fleshed sweet potato.

2. Materials and Methods

2.1 Raw Material and Processing

Sweet potato was used as drying material in this study. Samples of the local variety of sweet potato with pale flesh and white skin, heavily consumed in low-income households, were purchased during the period of July 2023 at the fruit and vegetable market in the town of Bobo Dioulasso (11 ° 11′ 00″ North, 4° 17′ 00″ West), located in the Haut Bassin region of Burkina Faso. Sweet potato samples were transported and stored in refrigerated conditions (4 ± 0.5 °C) before the drying process at the laboratory of materials of Helio physics and environment of the Nazi BONI University from Nazi Boni University. Before drying, sweet potato samples were placed in the laboratory to reach room temperature (25 ± 1°C). Sweet potato samples were selected, washed, peeled, cut into spheres with diameters from 1 ± 0.002 cm to 3 ± 0.002 cm, measured manually using a digital calliper. Spherical samples are immersed in distilled water to remove excess surface starch film. Excess water on the spherical samples was removed using blotting paper, and these sweet potato spheres were arranged in a single layer on a drying tray. The initial moisture content on a dry basis (d.b.) of sweet potato was determined using the convective oven method at 105 ± 5 ° C for 24 h (Compaoré et al., 2019). Triplicate samples were used to determine the moisture content and the average values were 2.259 $kg_{water}/kg_{dry\ matter}$.

2.2 Drying Equipment

Drying experiments were carried out in a laboratory oven (Froilabo, Model AC Standard Version, France, range 10 to 250 ° C with an accuracy of ±0.5°C) installed in the laboratory of materials of Helio physics and environment of the Nazi BONI University from Nazi Boni University., Bobo-Dioulasso, Burkina Faso, previously described by Ouoba et al. (2021). Length, height and width of oven were 0.579 m, 0.640 m and 0.526 m respectively. The oven essentially consisted of a centrifugal fan to provide the desired drying air flow, a 1,000-watt electric heater controlling the temperature of the drying air, an air filter and a proportional-integral-derivative controller (PID controller). Air temperature in convective oven was regulated to ±1∘C using a temperature controller. The oven operated at dry bulb temperatures of 10°C to 250°C. The desired drying air temperature was achieved by electrical resistance and controlled by the heating control unit. The air velocity was controlled by the centrifugal fan and a fan velocity control unit. Air passed from the heating unit and was heated to the desired temperature, and then channelled to the drying chamber through ventilation slots located in the rear side wall of the drying chamber. Fan located at the rear of chamber wall produced greater airflow and more intensive horizontal forced air circulation to dry the product samples. The samples were dried in a square perforated stainless-steel tray, which has a flow section of 0.3 m x 0.3 m. The oven was adjusted to the selected temperature for approximately 0.5 h prior to the start of the experiments to reach steady-state conditions.

2.3 Drying Procedure

Air drying temperatures were 50, 60, 70 and 80°C and air relative humidities were 5 to 20%. The air velocity was kept at a constant value of 1 to 2.0 m/s with an accuracy of ±0.03 m/s for all drying experiments. The drying process began when the drying conditions reached constant air temperatures. Once the parboiler reached stable conditions for the set points, the sweet potato samples were placed on a tray in a single layer, and the measurement started from that point. Experiments were carried out with 125 ± 0.3 g of sweet potato for all tests. The tray was removed from the convective dryer regularly, at 20-minute intervals, weighed with a digital electronic balance and then placed back in the oven. The digital electronic balance (model 2102, SARTORIUS, France, range 0 to 2,100 g with an accuracy of ±0.001 g) was kept very close to the dryer (less than 1 m) (Wang et al., 2022). Convective drying was continued until there was no significant variation in the change in the masses of sweet potatoes. The drying tests were terminated when the masses of the samples stabilized, which assumes that thermodynamic equilibrium is reached. The dried samples were cooled under laboratory conditions after each drying experiment and stored in airtight jars. The mass loss of the sample during drying was converted to the moisture content on a dry basis and expressed as kg_{water} / $kg_{dry\ matter}$ according to Equation (1). For each drying condition, averages of three replicates were taken as drying data. At the end of each experiment, the sample was heated in an oven at 105°C for 24 h of drying to obtain the dry matter mass of this sample (Compaoré et al., 2022).

$$X(t) = \frac{m(t) - m_s}{m_s} \quad (1)$$

Where X(t) is dry-based moisture content (d.b.) expressed in $kg_{water}/kg_{dry\ matter}$; m (t), mass of the wet product, expressed in kg at time t and m_s, dry matter mass of the sample (kg).

3. Drying Theory

3.1 Moisture Ratio

The moisture ratio (MR) was calculated from the mass loss data of the samples during drying. Equation (2) was used to calculate the moisture ratio (Doymaz, 2011a):

$$MR = \frac{X - X_e}{X_0 - X_e} \quad (2)$$

Where X, X_0 and X_e are respectively mean moisture content at any time of drying ($kg_{water}/kg_{dry\ matter}$), initial mean moisture content ($kg_{water}/kg_{dry\ matter}$) and equilibrium moisture content ($kg_{water}/kg_{dry\ matter}$).

As Xe is much lower than X_0 and X, it is negligible in this study. Then the moisture ratio becomes:

$$MR = \frac{X}{X_0} \tag{3}$$

3.2 Mathematical Modelling

Process modelling and optimization of process parameters can significantly reduce the number of experiments required for process design. Drying process modelling can be formally characterized by two different approaches: physical-based modelling and empirical modelling. Physical models describe the fundamentals of heat and mass transfer during the drying process. This modelling approach requires the knowledge of heat and mass transfer parameters, such as the effective diffusion coefficient in both solid and gas phases, thermal conductivity, specific heat capacity, density, etc., and the change caused by material shrinkage during the drying process. An alternative to physical-based modelling is experimental-based empirical modelling (Royen et al., 2020). In the literature, many empirical mathematical models applicable for the drying of food and agricultural products can be found; various authors have studied the modelling of the food drying process, for example hot-air drying of crabapple slices (Jiang et al., 2022), thin-layer drying of onion slices (Sobowale et al., 2020), thin-layer drying of scent leaves and lemon basil leaves (Mbegbu et al., 2021), convective and microwave drying of tomato slices (Guemouni et al., 2022), drying of lemon grass leaves (Olabinjo, 2022) and thin-layer drying of Easter lily scales (Wang et al., 2022).

In order to establish these empirical mathematical models during convective drying, following considerations were taken into account: process was isothermal, main mass transfer mechanism was by water diffusion, water diffusion was radial and deformations and shrinkage of sample during drying were assumed to be negligible. The convective drying of food and agricultural products carried out during the drying period with a a falling rate of the characteristic curve. Under these thin layer assumptions, various mathematical models were reported to study the modelling of thin-layer drying kinetics of root tubers. For this purpose, experimental data of the moisture ratio obtained at air drying temperatures and sample diameters of sweet potato spheres are fitted by (43) different drying models being in the thin layer drying literature of food and agricultural products, as shown in Table 1. These mathematical models are frequently used to adapt semi-empirical and empirical correlations describing the drying behaviour of food and agricultural products. These thin-layer models, which express the moisture ratio (MR) as a function of time (t), are used to capture the drying curves behaviours of sweet potato spheres (Guemouni et al., 2022).

Table 1: Mathematical models tested for the drying of sweet potatoes.

Names	Equations	References
1. Newton	$MR = \exp(-kt)$	(Hu et al., 2022)
2. Page	$MR = \exp(-kt^n)$	(Ayonga et al., 2023)
3. Modified Page-II	$MR = \exp[-(kt)^n]$	(Olabinjo, 2022)
4. Modified Page-III	$MR = a\exp[-(kt^n)]$	(Guemouni et al., 2022)

5. Modified Page-VI	$\mathrm{MR} = \exp(\mathrm{kt}^{\mathrm{n}})$	(Ayonga et al., 2023)
6. Modified Page-VII	$\mathrm{MR} = \exp[-\mathrm{k}(\mathrm{t}/L^2)^{\mathrm{n}}]$	(Alibas et al., 2020)
7. Modified Page-VIII	$\mathrm{MR} = \exp[-(k\,\mathrm{t}/L^2)^{\mathrm{n}}]$	(Pardeshi & Chattopadhyay, 2010)
8. Otsura et al.	$\mathrm{MR} = 1 - \exp[-(kt^n)]$	(Ertekin & Firat, 2017)
9. Simplified Fick	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{k}\,\mathrm{t}/L^2)$	(Guemouni et al., 2022)
10. Henderson et Pabis	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{kt})$	(Sharifian et al., 2023)
11. Modified Henderson and Pabis-I	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{kt}) + \mathrm{b}\exp(-\mathrm{gt}) + \mathrm{c}\exp(-\mathrm{ht})$	(Gasa et al., 2022)
12. Modified Henderson and Pabis-II	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{k}t^n) + \mathrm{b}\exp(-\mathrm{gt}) + \mathrm{c}\exp(-\mathrm{ht})$	(Ertekin & Heybeli, 2014)
13. Logarithmic model	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{kt}) + \mathrm{c}$	(Sharifian et al., 2023)
14. Two Term	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{k_1t}) + \mathrm{b}\exp(-\mathrm{k_2t})$	(Hu et al., 2022)
15. Modified two term-I	$\mathrm{MR} = \mathrm{a}\exp(\mathrm{k_0t}) + (1-\mathrm{a})\exp(-\mathrm{k_1t})$	(Ertekin & Heybeli, 2014)
16. Modified two term-II	$\mathrm{MR} = \mathrm{a}\exp(\mathrm{k_0t}) + (1-\mathrm{a})\exp(\mathrm{k_1t})$	(Ertekin & Firat, 2017)
17. Modified two term-III	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{k_0t}) + a\exp(-\mathrm{k_1t})$	(Ertekin & Heybeli, 2014)
18. Modified two term-IV	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{k_0}t^n) + b\exp(-\mathrm{k_1t})$	(Ertekin & Heybeli, 2014)
19. Modified two term-V	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{k_0}t) + (1-a)\exp(-\mathrm{k_1t})$	(Ertekin & Firat, 2017)
20. Two term Exponential	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{kt}) + (1-\mathrm{a})\exp(-\mathrm{kat})$	(Haydary et al., 2024)
21. Verma et al.	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{kt}) + (1-\mathrm{a})\exp(-\mathrm{gt})$	(Bryś et al., 2021)
22. Diffusion Approach	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{kt}) + (1-\mathrm{a})\exp(-\mathrm{kbt})$	(Haydary et al., 2024)
23. Midilli et al.	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{k}t^n) + \mathrm{bt}$	(Man et al., 2024)
24. Modified Midilli et al.-I	$\mathrm{MR} = \exp(-\mathrm{k}t^n) + \mathrm{bt}$	(Gasa et al., 2022)

25.	Modified Midilli et al.-II	$\mathrm{MR} = \exp(-kt) + \mathrm{bt}$	(Çerçi et al., 2018)
26.	Modified Midilli et al.-III	$\mathrm{MR} = \mathrm{a}\exp(-kt) + \mathrm{bt}$	(Ertekin & Firat, 2017)
27.	Hii et al.	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{bt}^c) + \mathrm{d}\exp(-\mathrm{gt}^c)$	(Aranha et al., 2024)
28.	Weibull-I	$\mathrm{MR} = \mathrm{a} - \mathrm{b}\exp[-kt^n]$	(Man et al., 2024)
29.	Weibull-III	$\mathrm{MR} = \exp\left[-\left(\frac{t}{b}\right)^a\right]$	(Xie et al., 2023)
30.	Jena and Das	$\mathrm{MR} = \mathrm{a}\exp\left(-\mathrm{kt} + \mathrm{b}t^{\frac{1}{2}}\right) + \mathrm{c}$	(Kusuma et al., 2023)
31.	Haghi and Angiz-I	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{b}t^c) + dt^2 + et + f$	(Ertekin & Firat, 2017)
32.	Haghi and Angiz-III	$\mathrm{MR} = \frac{a+bt}{1+ct+dt^2}$	(Ertekin & Firat, 2017)
33.	Sripinyowanich and Noomhorm	$\mathrm{MR} = \exp(-kt^n) + bt + c$	(Sitorus et al., 2021)
34.	Noomhorm and Verma	$\mathrm{MR} = \mathrm{a}\exp(-kt) + b\exp(-\mathrm{g}t) + c$	(Bryś et al., 2021)
35.	Hasibuan and Daud	$\mathrm{MR} = 1 - \mathrm{a}\,t^n\exp(-kt^m)$	(Ertekin & Heybeli, 2014)
36.	Henderson and Henderson-I	$\mathrm{MR} = \mathrm{c}\left[\exp(-kt) + \frac{1}{9}\exp(-9kt)\right]$	(Ertekin & Heybeli, 2014)
37.	Henderson and Henderson-II	$\mathrm{MR} = \mathrm{c}\exp(-kt) + \frac{1}{9}\exp(-9kt)$	(Ertekin & Heybeli, 2014)
38.	Logistic model	$\mathrm{MR} = a_0/[1 + \mathrm{a}\exp(kt)]$	(Bousselma et al., 2021)
39.	Aghbashlo	$\mathrm{MR} = \exp\left(-\frac{k_1 t}{1+k_2 t}\right)$	(Okunola et al., 2023)
40.	Three-parameter model	$\mathrm{MR} = \mathrm{a}\exp[-(kt)^n]$	(Ertekin & Firat, 2017)
41.	Asymptotic model	$\mathrm{MR} = a_0 + \mathrm{a}\exp(-kt)$	(Nsibi & Lajili, 2023)
42.	Khazaei and Daneshmandi	$\mathrm{MR} = \mathrm{a} + \exp(-bt) - ct$	(Ertekin & Firat, 2017)
43.	Sigmoid model	$\mathrm{MR} = \mathrm{a} + \frac{\mathrm{b}}{1+e^{k(t-c)}}$	(Simsek & Süfer, 2021)

Note: MR is dimensionless moisture ratio; *a, b, c, d, h, g* = empirical model constant (dimensionless), k, k_1, k_2 =drying constant obtained from experimental data (s^{-1}), *n* = empirical model constant (dimensionless), *L* = diameter (*m*) and *t* = time (*s*).

3.3 Statistical Analysis

For the modeling of the drying kinetics, a nonlinear regression analysis was performed using MATLAB software 8.0. Four statistical parameters were used to determine the ability of the tested model to represent the experimental data, namely: the determination coefficient (R^2), the Root Mean Square Error (RMSE) and the Sum of Squared Errors (SSE).

- The coefficient of determination(R^2)

R^2 is used in the context of statistical models whose main purpose is to predict of future outcomes on the basis of other related information. It is the proportion of variability in a data set that is accounted for by statistical model. Provides a measure of how well future outcomes are likely to be predicted by the model. The coefficient of determination is not likely to be 0 or 1, but rather somewhere in between these limits. Closer it is to 1, greater relationship exists between experimental and predicted values. This value is used for comparison criteria and shows the level of agreement between measured and predicted values (Ertekin & Firat, 2017). It was one of the first criteria used to select the appropriate model to describe the behavior of drying of fruits and vegetables (Mota et al., 2010).

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(P_{exp,i} - P_{pre,i}\right)^2}{\sum_{i=1}^{N}\left(\bar{P}_{exp} - P_{exp,i}\right)^2} \tag{5}$$

- Root Mean Square Error (RMSE)

The root mean square deviation, RMSD, or the root mean square error, RMSE, is a frequently used measure of differences between values predicted by a model or an estimator and values actually observed from something being modeled or estimated. RMSD is a good measure of accuracy and serves to aggregate residuals into a single measure of predictive power. It is required to reach zero and can be calculated as (Compaoré et al., 2022) :

$$RMSE = \left[\frac{\sum_{i=1}^{N}\left(P_{exp,i} - P_{pre,i}\right)^2}{N}\right]^{1/2} \tag{6}$$

- Sum of Squared Errors, SSE

SSE is the measure of the deviation of a sample from its 'theoretical value'. This parameter is defined as the difference between experimental and predicted data and defined as (Doymaz, 2012):

$$SSE = \sum_{i=1}^{N}\left(P_{exp,i} - P_{pre,i}\right)^2 \tag{8}$$

Where P is the setting for drying given, $P_{exp,I}$ is the experimental value of the parameter, $P_{pre,I}$ is the value predicted by the parameter P , $\bar{P}_{exp,i}$, is the average value of the parameter P, N is the number of observations and z is the number of constants in each regression. Goodness of fit was found where R^2 was highest and lowest values of RMSE, χ^2 and SSE were found (Compaoré et al., 2022).

4. Results and Discussion

4.1 Evaluation of Drying Mathematical Models

Mathematical modelling of the drying process is an important aspect of drying technology without or with pretreatment of food materials. It is important to perform mathematical modelling of drying kinetics to incorporate experimental research data on food drying in industrial and/or semi-artisanal applications. Various mathematical models have been reported in the literature to study the modelling of thin-film food drying kinetics. To better evaluate the model that interprets our experimental drying data, 43 mathematical models (Table 1) were tested and evaluated to select the best based on the following parameters: coefficient of determination (R^2), Sum of Squared Errors (SSE) and RMSE (Guemouni et al., 2022). The mathematical drying models were evaluated as follows. Moisture content data obtained for different drying air temperatures and for different diameters of spherical sweet potato samples were converted into dimensionless moisture ratio expressions (equation (2)). Then, the calculations for fitting these experimental data by non-linear regression analysis with drying time were carried out successively one after the other on the mathematical models in Table 1. A curve fitting toolbox, MATLAB R2023b programming software, was used to perform these adjustments on the experimental data. On the basis of this, the constant parameters of the examined models and their adjustment coefficients (R^2, SSE, and RMSE) were obtained. Based on the values of R^2, RMSE, and SSE, the adequacy of the mathematical models tested to the experimental data was evaluated. The best model to describe the drying process was determined by the model with the lowest SSE and RMSE value, and the highest R^2 value. These statistical parameters have constantly been used in previous studies to evaluate their models by many researchers (Guemouni et al., 2022; Jiang et al., 2022; Kardile et al., 2020; Mbegbu et al., 2021; Olabinjo, 2022; Royen et al., 2020; Sobowale et al., 2020; Wang et al., 2022). Babatunde *et al.* (2018) , Compaoré *et al.* (2022) and Sommete *et al.* (2017) reported that a higher value of R^2 and lower value of RMSE and SSE should be the characteristics for selection of a model for prediction of drying behaviour.

The results of the statistical analyses applied to the mathematical models of taking into account the air-drying temperature values and the diameter sizes of the samples are given in Table 2. From the result of Table 2 the value of R^2, SSE and RMSE ranged from 0.8823 - 0.9999, 0.0005 - 0.5408 and 0.0021 - 0.0711 respectively for 2-3 cm diameter samples and 50-80°C air drying temperatures. It is observed from Table 2 that almost all models had R^2 greater than 0.90 which shows their competitive fit to the drying data of sweet potato spherical samples. The lowest (0.8823) R^2 value was observed at 50°C air temperature for a 2 cm diameter samples with the Newton model, while the least (0.0005) SSE value and (0.0021) RMSE value were observed at 70°C air temperature for a 3 cm diameter samples with Haghi and Angiz-I model. The highest value (0.9999) R^2 was observed with four models (Haghi and Angiz-I, modified Henderson and Pabis-I, modified two term IV and Haghi and Angiz-III) at air temperatures of 70 ° C for samples of 3 cm diameter. Concerning the highest (0.5408) SSE value and highest (0.0711) RMSE value, they were observed all with the same Modified two term-III model at 60°C air temperature for a 2 cm diameter samples. Hence, sweet potato spherical samples can best be dried at 70°C with 3 cm diameters.

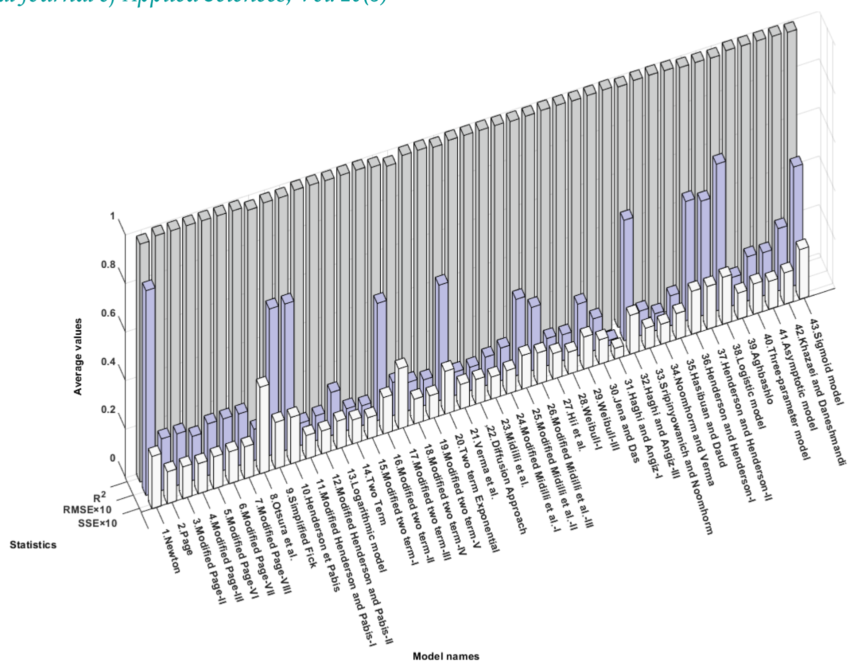


Fig. 1: Average values of statistic parameters for hot air drying spherical sweet potatoes.

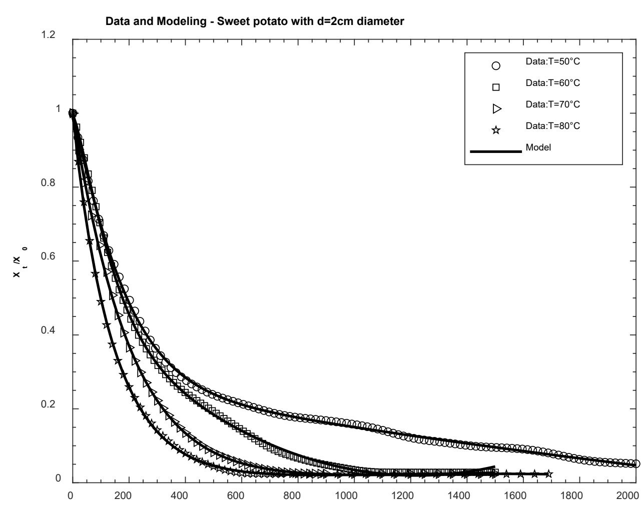
For satisfying the conditions for selecting the most suitable and reliable model, the average values of R^2, SSE and RMSE for all drying models are shown in Table 2 and Fig. 1. Haghi and Angiz-I model offering maximum average value of R^2 and minimum average value of RMSE and SSE namely 0.999587, 0.004375 and 0.002175 respectively as shown in this Table and Figure. The accuracy of the fitting of the Haghi and Angiz-I model was better than that of the others model, shown in Table 2 becoming the most suitable model for drying spherical sweet potato samples. Therefore, with these best performances in fitting the experimental data, it can be assumed that the Haghi and Angiz I model represents the drying behaviour of 2-3 cm diameter spherical sweet potato samples at air temperatures of 50-80°C. This model can be used satisfactorily to predict the experimental moisture ratio values of these sweet potato varieties. Various authors in the drying of fruits and vegetables obtained similar findings. The Haghi and Angiz-I model has also been suggested by other researchers to describe the drying of mint leaves (Ertekin & Heybeli, 2014); zucchini (Çerçi et al., 2018); white sweet cherry (Simsek & Süfer, 2021); paddy (Sitorus et al., 2021); whole apricots (Bousselma et al., 2021); titanium slag (Ren et al., 2024); coffee beans (Antunes et al., 2024) and apple slices (El-Mesery et al., 2024).

Equivalent models have been already revealed in other studies but the suitable models may differ depending on the applied drying process and the used wet solid matters. Gasa *et al.* (2022) have shown the suitability of Midilli *et al.* model in describing the drying kinetics of sweet potato slices under naturally-ventilated warm air by solar-venturi dryer. Falade and Solademi (2010) found that the Page model was most adequate in describing the air-drying processes of fresh and pretreated (blanched) sweet potato slices. Doymaz (2011b) investigated that the logarithmic model had described well drying characteristics of sweet potato slices at 50, 60 and 70°C. Singh and Pandey (2012) showed that the Page model gave better prediction than the first order kinetics of Henderson and Pabis model and satisfactorily described drying characteristics of sweet potato cubes. (Zhu & Jiang (2014) obtained that the Wang and Singh model may be selected to represent the thin layer drying behaviour of sweet potato slices for 0.423 -1.120 m/s air velocity and 2-4 mm thickness. Fan et al., (2015) observed that the Hii *et al.* model was selected as a suitable model to describe the characteristics of thin layer drying of sweet potato slices for 3-8 mm thickness. Ayonga et al., (2023) noticed that the Page model was found to be the best model for untreated samples of orange-fleshed sweet potato, while the logarithmic model best described the drying behaviour of all the pretreated samples. Three different pretreatments (lemon juice, salt solution and hot water blanching) carried out in 3-mm thick slices. The differences of drying models between the modelling results can be explained by effect of method drying, type, composition, and molecular characteristics of the sweet potatoes.

4.2 Model Validation

To validate the suitability of the Haghi and Angiz-I model, Fig. 2 shows the suitability of the model to predict the values of the experimental moisture ratio with drying time for samples of 2-3 cm in diameter at air drying temperatures of 50-80 ° C. The nature of the experimental versus predicted moisture ratio for the operational conditions, as shown in Fig. 3, clearly shows that there was very good agreement between the experimental and predicted moisture ratio values, as the data points have been arranged in a straight line with an angle of 45 ° to the horizontal axis. As a consequence, it can be confirmed that the thin layer model is appropriate for predicting the convective drying behaviour of sweet potato spheres. Similar concordances were reported for mushroom drying (Nadew et al., 2024), cabbage drying (Luka et al., 2024) and drying apple slices (El-Mesery et al., 2024) and drying mango (Gebre et al., 2024).

(a)



(b)

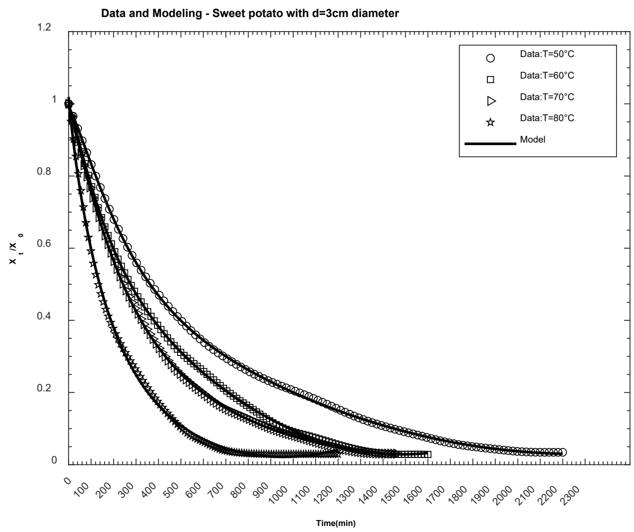
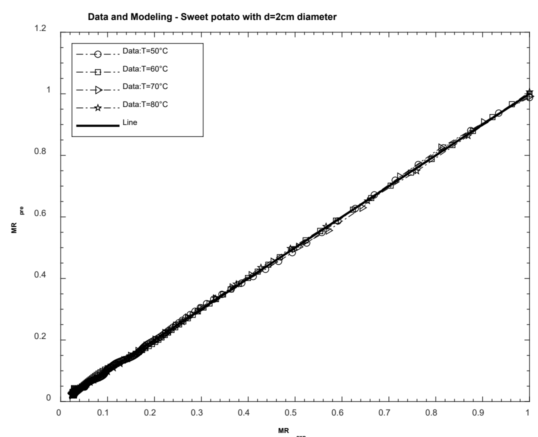


Fig. 2: Variation of moisture ratio with drying time from by Haghi and Angiz-I model and experimental data.

(a)



(b)

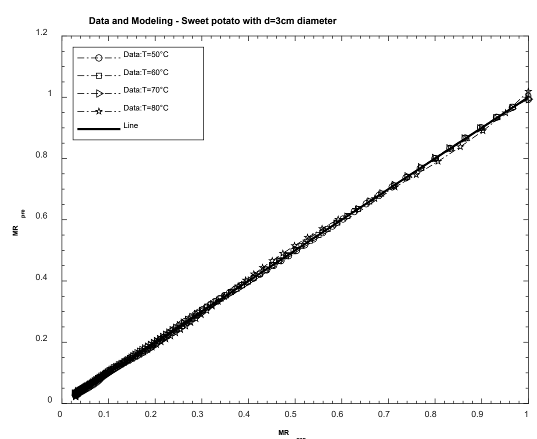


Fig. 3: Experimental and predicted moisture ratio values at 50-80°C temperatures for Haghi and Angiz-I model.

The drying constant (b) increased generally with increasing of air-drying temperature. This could be attributed to higher drying temperature, which increases the driving force of heat and mass transfer. This implied also that the increase in convective drying kinetics became steeper indicating the increase in drying rate. The model equations for drying of 2-3 cm diameter sweet potato spheres at drying temperatures of 50-80 ° C are expressed below.

For 2 cm diameter samples:

$$T = 50°C: MR = 0.7148e^{\left(-0.00244\mathrm{t}^{1.1518}\right)} + 1.016 \times 10^{-8}t^2 - 1.333 \times 10^{-4}\mathrm{t} + 0.2730 \quad (9a)$$

$$T = 60°C: MR = 0.5145e^{\left(-0.001364\mathrm{t}^{1.3255}\right)} + 3.115 \times 10^{-7}t^2 - 7.608 \times 10^{-4}\mathrm{t} + 0.4841 \quad (9b)$$

$$T = 70°C: MR = 0.9914e^{\left(-0.003927\mathrm{t}^{1.0442}\right)} + 3.102 \times 10^{-9}t^2 + 1.3 \times 10^{-5}\mathrm{t} + 3.725 \times 10^{-4} \quad (9c)$$

$$T = 80°C: MR = 1.0291e^{\left(-0.008829\mathrm{t}^{0.9478}\right)} + 2.157 \times 10^{-8}t^2 + 6.367 \times 10^{-5}\mathrm{t} - 0.02292 \quad (9d)$$

For 3 cm diameter samples:

$$T = 50°C: MR = 0.4196e^{\left(-0.0009197\mathrm{t}^{1.263}\right)} + 1.063 \times 10^{-7}t^2 + 4.806 \times 10^{-4}\mathrm{t} + 0.5735 \quad (10a)$$

$$T = 60°C: MR = 0.3466e^{\left(-0.002107\mathrm{t}^{1.2}\right)} + 2.82 \times 10^{-7}t^2 + 8.386 \times 10^{-4}\mathrm{t} + 0.6524 \quad (10b)$$

$$T = 70°C: MR = 0.6324e^{\left(-0.002121\mathrm{t}^{1.122}\right)} + 1.244 \times 10^{-7}t^2 - 4.112 \times 10^{-4}\mathrm{t} + 0.3614 \quad (10c)$$

$$T = 80°C: MR = 0.7627e^{\left(-0.009928\mathrm{t}^{0.9138}\right)} + 2.833 \times 10^{-7}t^2 - 5.204 \times 10^{-4}\mathrm{t} + 0.2566 \quad (10d)$$

Conclusion

The mathematical modelling of sweet potato spheres was investigated at 50°C, 60°C,70°c and 80°C air temperatures for 2 and 3 cm diameter samples using a convective oven dryer. For this purpose, forty-three (43) mathematical models were used to estimate the drying coefficients following nonlinear regression method to find the best fit of the moisture ratio models obtained from experimental database on the following parameters: coefficient of determination (R^2), Sum of Squared Errors (SSE) and Root Mean Square Error (RMSE).In experiments, different sweet potato spheres were dried at different drying air temperature conditions, and moisture content changes were recorded during the drying time. They were converted to the moisture ratio values and used to model the convective drying behaviour of sweet potato spheres. Concerning modelling results, it is obtained that almost the models had R^2 greater than 0.90 which shows their competitive fit to the drying data of sweet potato spherical samples. Based on statistic parameters, sweet potato spherical samples can best be dried at 70°C with 3 cm diameters. The Haghi and Angiz-I model was the best fit to predict the moisture ratio of the sweet potato spherical samples dried in the hot air oven dryer based on average values from statistical analysis (R^2 =0.999587, RMSE =0.004375 and SSE =0.002175). The results of this study are useful to optimize drying process parameters for commercial-scale production of dried sweet potatoes using a convective oven dryer and to achieve superior quality of the dried products.

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

	Diameters	2 cm				3 cm				Global
Model names	Parameters	50°C	60°C	70°C	80°C	50°C	60°C	70°C	80°C	
1. Newton	$MR = \exp(-kt)$									
	k	0.0026	0.0036	0.0049	0.0067	0.0017	0.0024	0.0027	0.0047	
	R^2	0.8823	0.9942	0.9979	0.9950	0.9943	0.9982	0.9981	0.9943	0.981787
	RMSE	0.0690	0.0183	0.0112	0.0160	0.0188	0.0109	0.0110	0.0178	0.021625
	SSE	0.5193	0.0364	0.0071	0.0144	0.0384	0.0129	0.0132	0.0346	0.084537
2. Page	$MR = \exp(-kt^n)$									
	k	0.0237	0.0058	0.0051	0.0098	0.0032	0.0031	0.0038	0.0078	
	n	0.6412	0.9168	0.9949	0.9274	0.9044	0.9587	0.9439	0.9081	
	R^2	0.9792	0.9967	0.9979	0.9964	0.9984	0.9989	0.9993	0.9972	0.9955
	RMSE	0.0291	0.0139	0.0113	0.0138	0.0100	0.0087	0.0065	0.0125	0.013225
	SSE	0.0916	0.0210	0.0070	0.0104	0.0108	0.0081	0.0046	0.0168	0.021287
3. Modified Page-II	$MR = \exp[-(kt)^n]$									
	k	0.0029	0.0036	0.0050	0.0068	0.0018	0.0024	0.0028	0.0048	
	n	0.6412	0.9168	0.9949	0.9274	0.9044	0.9587	0.9439	0.9081	
	R^2	0.9792	0.9967	0.9979	0.9964	0.9984	0.9989	0.9993	0.9972	0.9955
	RMSE	0.0291	0.0139	0.0113	0.0138	0.0100	0.0087	0.0065	0.0125	0.013225
	SSE	0.0916	0.0210	0.0070	0.0104	0.0108	0.0081	0.0046	0.0168	0.021287

4. Modified Page-III	$MR = a\exp[-(kt^{n})]$									
	a	1.0991	1.0458	1.0026	1.0142	1.0218	1.0001	1.0222	1.0236	
	k	0.0357	0.0079	0.0052	0.0108	0.0038	0.0031	0.0046	0.0092	
	n	0.5888	0.8711	0.9916	0.9123	0.8808	0.9586	0.9186	0.8834	
	R^2	0.9829	0.9974	0.9979	0.9965	0.9986	0.9989	0.9995	0.9974	0.996137
	RMSE	0.0265	0.0124	0.0114	0.0137	0.0094	0.0087	0.0055	0.0121	0.012462
	SSE	0.0752	0.0164	0.0070	0.0102	0.0095	0.0081	0.0033	0.0156	0.018162
5. Modified Page-VI	$MR = \exp(kt^{n})$									
	k	-0.0237	-0.0058	-0.005	-0.0098	-0.0032	-0.0031	-0.0038	-0.0078	
	n	0.6412	0.9168	0.9949	0.9274	0.9044	0.9587	0.9439	0.9081	
	R^2	0.9792	0.9967	0.9979	0.9964	0.9984	0.9989	0.9993	0.9972	0.9955
	RMSE	0.0291	0.0139	0.0113	0.0138	0.0100	0.0087	0.0065	0.0125	0.013225
	SSE	0.0916	0.0210	0.0070	0.0104	0.0108	0.0081	0.0046	0.0168	0.021287
6. Modified Page-VII	$MR = \exp[-k(t/L^{2})^{n}]$									
	k	0.0577	0.0206	0.0202	0.0355	0.0234	0.0253	0.0305	0.0575	
	n	0.6412	0.9168	0.9949	0.9274	0.9044	0.9587	0.9439	0.9081	
	R^2	0.9792	0.9967	0.9979	0.9964	0.9984	0.9989	0.9993	0.9972	0.9955
	RMSE	0.0291	0.0139	0.0113	0.0138	0.0100	0.0087	0.0065	0.0125	0.013225
	SSE	0.0916	0.0210	0.0070	0.0104	0.0108	0.0081	0.0046	0.0168	0.021287
7. Modified Page-VIII	$MR = \exp[-(k\,t/L^{2})^{n}]$									

	k	0.0117	0.0145	0.0198	0.0273	0.0158	0.0216	0.0248	0.0430	
	n	0.6412	0.9167	0.9949	0.9274	0.9044	0.9587	0.9439	0.9081	
	R^2	0.9792	0.9967	0.9979	0.9964	0.9984	0.9989	0.9993	0.9972	0.9955
	RMSE	0.0291	0.0139	0.0113	0.0138	0.0100	0.0087	0.0065	0.0125	0.013225
	SSE	0.0916	0.0210	0.0070	0.0104	0.0108	0.0081	0.0046	0.0168	0.021287
8. Otsura et al.	$MR = 1 - \exp[-(kt^n)]$									
	k	71.9340	388.807	522.9090	200.570	506.428	508.463	460.833	249.416	
	n	-0.8924	-1.2371	-1.3613	-1.2608	-1.1326	-1.1936	-1.2046	-1.2187	
	R^2	0.9929	0.9807	0.9750	0.9808	0.9737	0.9666	0.9769	0.9732	0.977475
	RMSE	0.0170	0.0336	0.0388	0.0318	0.0406	0.0471	0.0386	0.0388	0.035787
	SSE	0.0312	0.1220	0.0826	0.0557	0.1778	0.2397	0.1610	0.1628	0.1291
9. Simplified Fick's model.	$MR = k \exp[-c\,(t/L^2)]$									
	c	0.0081	0.0139	0.0198	0.0263	0.0148	0.0209	0.0241	0.0406	
	k	0.8181	0.9799	0.9995	0.9807	0.9608	0.9805	0.9824	0.9655	
	R^2	0.9200	0.9946	0.9979	0.9953	0.9961	0.9986	0.9984	0.9953	0.987025
	RMSE	0.0572	0.0178	0.0113	0.0157	0.0157	0.0096	0.0101	0.0162	0.0192
	SSE	0.3530	0.0342	0.0071	0.0135	0.0267	0.0100	0.0110	0.0284	0.060487
10. Henderson et Pabis	$MR = a \exp(-kt)$									
	a	0.8182	0.9799	0.9995	0.9807	0.9608	0.9805	0.9824	0.9655	
	k	0.0020	0.0035	0.0049	0.0066	0.0016	0.0023	0.0027	0.0045	

	R^2	0.9200	0.9946	0.9979	0.9953	0.9961	0.9986	0.9984	0.9953	0.987025
	RMSE	0.0572	0.0178	0.0113	0.0157	0.0157	0.0096	0.0101	0.0162	0.0192
	SSE	0.3530	0.0342	0.0071	0.0135	0.0267	0.0100	0.0110	0.0284	0.060487
11. Modified Henderson and Pabis-I	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$									
	a	3.5992	4.6687	0.6578	7.0438	12.9720	0.1739	0.7196	1.6011	
	b	-2.9632	-3.9849	0.9993	0.9668	0.8306	1.2859	0.5102	0.9577	
	c	0.3538	0.3507	0.6571	-7.0107	-12.805	-0.4459	-0.2304	-1.5588	
	g	0.0107	0.0032	0.0049	0.0065	0.0015	0.0017	0.0068	0.0045	
	h	0.0009	0.0081	1.2523	0.6263	0.0105	0.0011	0.0106	1.1665	
	k	0.0095	0.0031	0.7023	0.6617	0.0104	0.0079	0.0022	2.1918	
	R^2	0.9989	0.9980	0.9979	0.9956	0.9993	0.9995	0.9999	0.9956	0.998087
	RMSE	0.0068	0.0111	0.0118	0.0159	0.0070	0.0059	0.0027	0.0161	0.009662
	SSE	0.0048	0.0127	0.0071	0.0129	0.0051	0.0036	0.0007	0.0269	0.009225
12. Modified Henderson and Pabis-II	$MR = a\exp(-kt^n) + b\exp(-gt) + c\exp(-ht)$									
	a	1.4578	1.2122	1.4560	1.0040	0.7987	1.0045	1.0362	0.0138	
	b	0.3126	0.4240	0.2335	0.0195	0.3696	1.2749	-0.6525	0.1113	
	c	-0.7704	-0.6356	-0.6855	-0.0230	-0.1728	-1.2809	0.6163	0.8910	
	g	20.000	0.0768	0.0291	0.0000	0.0078	0.5715	1.4843	0.0195	
	h	0.5093	0.0657	0.0259	0.0687	0.0158	0.5986	0.8481	0.0045	
	k	0.0962	0.0172	0.0210	0.0095	0.0012	0.0032	0.0051	1.31×10^{-4}	

	n	0.4624	0.7600	0.7882	0.9471	1.0294	0.9518	0.9029	8.24×10^{-4}	
	R^2	0.9911	0.9986	0.9984	0.9995	0.9993	0.9989	0.9996	0.9982	0.99795
	RMSE	0.0195	0.0094	0.0101	0.0055	0.0069	0.0089	0.0049	0.0104	0.00945
	SSE	0.0391	0.0091	0.0051	0.0015	0.0048	0.0082	0.0025	0.0111	0.010175
13. Logarithmic	$MR = a\exp(-kt) + c$									
	a	0.8629	0.9785	0.9954	0.9758	0.9549	0.9807	0.9773	0.9637	
	c	0.0975	0.0225	0.0140	0.0206	0.0211	0.0007	0.0204	0.0193	
	k	0.0036	0.0038	0.0052	0.0071	0.0018	0.0023	0.0029	0.0049	
	R^2	0.9837	0.9973	0.9991	0.9996	0.9970	0.9986	0.9995	0.9975	0.996537
	RMSE	0.0259	0.0127	0.0072	0.0048	0.0138	0.0097	0.0057	0.0119	0.011462
	SSE	0.0718	0.0173	0.0028	0.0013	0.0203	0.0100	0.0035	0.0151	0.017762
14. Two Term	$MR = a\exp(-k_1t) + b\exp(-k_2t)$									
	a	0.7039	0.4638	0.9994	1.2057	0.8086	0.9420	0.4916	0.7995	
	b	0.3186	0.5662	5.1×10^{-4}	-0.2246	0.2091	0.0696	0.5180	0.2175	
	k_1	0.0060	0.0065	0.0049	0.0066	0.0014	0.0022	0.0020	0.0039	
	k_2	0.0008	0.0026	0.4966	0.0067	0.0053	0.0128	0.0040	0.0134	
	R^2	0.9978	0.9981	0.9979	0.9953	0.9990	0.9991	0.9998	0.9975	0.998062
	RMSE	0.0095	0.0107	0.0115	0.0160	0.0080	0.0078	0.0036	0.0119	0.009875
	SSE	0.0096	0.0120	0.0071	0.0135	0.0069	0.0064	0.0014	0.0151	0.009
15. Modified two term-I	$MR = a\exp(k_0t) + (1-a)\exp(-k_1t)$									

	a	0.3093	0.3391	0.9993	0.0161	0.7999	0.9436	0.3511	0.7517	
	k_0	-0.0008	-0.0021	-0.0049	0.0002	-0.0014	-0.0023	-0.0018	-0.0038	
	k_1	0.0057	0.0049	8.5000	0.0071	0.0047	0.0113	0.0035	0.0106	
	R^2	0.9975	0.9977	0.9979	0.9996	0.9989	0.9991	0.9998	0.9974	0.998487
	RMSE	0.0101	0.0116	0.0114	0.0047	0.0085	0.0079	0.0040	0.0121	0.008787
	SSE	0.0109	0.0144	0.0071	0.0012	0.0078	0.0067	0.0017	0.0156	0.008175
16. Modified two term-II	$MR = a\exp(k_0 t) + (1-a)\exp(k_1 t)$									
	a	0.7816	0.9755	0.0002	0.0161	0.7983	0.9438	0.3465	0.2521	
	k_0	-0.0019	-0.0035	-0.6601	0.0002	-0.0014	-0.0023	-0.0018	-0.0105	
	k_1	-9.3965	-10.799	-0.0049	-0.0071	-0.0047	-0.0113	-0.0035	-0.0038	
	R^2	0.9290	0.9947	0.9979	0.9996	0.9989	0.9991	0.9998	0.9974	0.98955
	RMSE	0.0541	0.0178	0.0114	0.0047	0.0085	0.0079	0.0040	0.0121	0.015062
	SSE	0.3132	0.0338	0.0071	0.0012	0.0078	0.0067	0.0017	0.0156	0.048387
17. Modified two term-III	$MR = a\exp(-k_0 t) + a\exp(-k_1 t)$									
	a	0.6696	0.7734	0.5029	0.5033	0.4998	0.4932	0.5049	0.5008	
	k_0	0.0016	0.0028	0.0042	0.0048	0.0012	0.0020	0.0040	0.0073	
	k_1	9.3965	10.7990	0.0060	0.0102	0.0027	0.0028	0.0020	0.0033	
	R^2	0.8865	0.9144	0.9980	0.9969	0.9983	0.9987	0.9998	0.9974	0.97375
	RMSE	0.0684	0.0711	0.0111	0.0129	0.0103	0.0094	0.0036	0.0122	0.024875
	SSE	0.5005	0.5408	0.0067	0.0089	0.0114	0.0096	0.0014	0.0159	0.1369

18. Modified two term-IV	$MR = a\exp(-k_0 t^n) + b\exp(-k_1 t)$									
	a	1.4584	1.0925	0.0147	0.0335	1.0494	0.4862	1.1395	1.0667	
	b	-0.4584	-0.0925	1.0007	0.9667	-0.0504	0.5280	-0.1363	-0.0675	
	k_0	0.0963	0.0105	1.3276	0.0023	0.0047	0.0000	0.0084	0.0118	
	k_1	9.3965	10.7990	0.0052	0.0065	0.0486	0.0055	0.0239	0.1102	
	n	0.4622	0.8291	-2.3466	3.2496	0.8543	1.5320	0.8342	0.8449	
	R^2	0.9911	0.9981	0.9992	0.9956	0.9987	0.9996	0.9999	0.9977	0.997487
	RMSE	0.0193	0.0108	0.0072	0.0157	0.0090	0.0050	0.0031	0.0116	0.010212
	SSE	0.0391	0.0122	0.0027	0.0129	0.0085	0.0026	0.0010	0.0142	0.01165
19. Modified two term-V	$MR = a\exp(-k_0 t) + (1-a)\exp(-k_1 t)$									
	a	0.3092	0.9755	0.9993	0.9792	0.8000	0.0561	0.6463	0.2489	
	k_0	0.0008	0.0035	0.0049	0.0072	0.0014	0.0114	0.0035	0.0106	
	k_1	0.0057	5.3843	8.5000	0.0000	0.0047	0.0023	0.0018	0.0038	
	R^2	0.9975	0.9947	0.9979	0.9996	0.9989	0.9991	0.9998	0.9974	0.998112
	RMSE	0.0101	0.0178	0.0114	0.0049	0.0085	0.0079	0.0040	0.0121	0.009587
	SSE	0.0109	0.0338	0.0071	0.0013	0.0078	0.0067	0.0017	0.0156	0.010612
20. Two term Exponential	$MR = a\exp(-kt) + (1-a)\exp(-kat)$									
	a	0.2745	0.0347	0.0032	0.0357	0.1067	0.0273	0.0238	0.0885	
	k	0.0071	0.0987	1.5272	0.1812	0.0143	0.0846	0.1115	0.0481	
	R^2	0.9396	0.9947	0.9979	0.9956	0.9973	0.9987	0.9985	0.9961	0.9898

	RMSE	0.0497	0.0176	0.0113	0.0153	0.0131	0.0092	0.0098	0.0148	0.0176
	SSE	0.2663	0.0333	0.0071	0.0128	0.0184	0.0092	0.0104	0.0238	0.047662
21. Verma et al.	$MR = a\exp(-kt) + (1-a)\exp(-gt)$									
	a	0.6910	0.6616	0.9993	0.0332	0.2013	0.0567	0.3552	0.2480	
	g	0.0008	0.0021	0.6560	0.0065	0.0014	0.0023	0.0035	0.0038	
	k	0.0057	0.0049	0.0049	0.4000	0.0047	0.0114	0.0018	0.0106	
	R^2	0.9975	0.9977	0.9979	0.9956	0.9989	0.9991	0.9998	0.9974	0.997987
	RMSE	0.0101	0.0116	0.0114	0.0154	0.0085	0.0079	0.0040	0.0121	0.010125
	SSE	0.0109	0.0144	0.0071	0.0129	0.0078	0.0067	0.0017	0.0156	0.009637
22. Diffusion Approach	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$									
	a	0.6909	0.6624	-0.0028	0.0333	0.2003	0.0563	0.6460	0.2493	
	b	0.1402	0.4368	0.2799	0.0227	0.3054	0.1986	0.5073	0.3632	
	k	0.0057	0.0049	0.0177	0.2858	0.0047	0.0113	0.0035	0.0106	
	R^2	0.9975	0.9977	0.9979	0.9956	0.9989	0.9991	0.9998	0.9974	0.997987
	RMSE	0.0101	0.0116	0.0114	0.0154	0.0085	0.0079	0.0040	0.0121	0.010125
	SSE	0.0109	0.0144	0.0071	0.0129	0.0078	0.0067	0.0017	0.0156	0.009637
23. Midilli et al.	$MR = a\exp(-kt^{n}) + bt$									
	a	1.0677	1.0346	0.9911	1.0060	1.0321	1.0144	1.0158	1.0102	
	b	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	k	0.0206	0.0064	0.0039	0.0088	0.0048	0.0042	0.0040	0.0072	

	n	0.6859	0.9086	1.0480	0.9529	0.8447	0.9055	0.9424	0.9272	
	R^2	0.9884	0.9979	0.9997	0.9997	0.9988	0.9993	0.9996	0.9981	0.997687
	RMSE	0.0220	0.0112	0.0042	0.0040	0.0087	0.0070	0.0050	0.0105	0.009075
	SSE	0.0513	0.0133	0.0009	0.0008	0.0080	0.0052	0.0026	0.0117	0.011725
24. Modified Midilli et al.-I	$MR = \exp(-kt^n) + bt$									
	b	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	k	0.0139	0.0048	0.0042	0.0085	0.0035	0.0036	0.0034	0.0067	
	n	0.7417	0.9514	1.0353	0.9597	0.8904	0.9282	0.9669	0.9403	
	R^2	0.9867	0.9975	0.9997	0.9997	0.9985	0.9992	0.9995	0.0105	0.873912
	RMSE	0.0234	0.0122	0.0044	0.0041	0.0098	0.0073	0.0055	0.9980	0.133087
	SSE	0.0588	0.0158	0.0011	0.0009	0.0102	0.0056	0.0032	0.0119	0.013437
25. Modified Midilli et al.-II	$MR = \exp(-kt) + bt$									
	b	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	k	0.0031	0.0037	0.0050	0.0069	0.0018	0.0024	0.0028	0.0048	
	R^2	0.9622	0.9969	0.9994	0.9993	0.9960	0.9982	0.9993	0.9972	0.993562
	RMSE	0.0393	0.0134	0.0059	0.0061	0.0159	0.0108	0.0066	0.0126	0.013825
	SSE	0.1666	0.0194	0.0019	0.0020	0.0273	0.0127	0.0047	0.0173	0.031487
26. Modified Midilli et al.-III	$MR = a\exp(-kt) + bt$									
	a	0.9131	0.9952	1.0072	0.9887	0.9716	0.9794	0.9944	0.9790	
	b	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	

	k	0.0028	0.0037	0.0051	0.0068	0.0017	0.0023	0.0028	0.0047	
	R^2	0.9696	0.9969	0.9995	0.9994	0.9967	0.9986	0.9994	0.9975	0.9947
	RMSE	0.0354	0.0134	0.0057	0.0057	0.0144	0.0096	0.0065	0.0119	0.012825
	SSE	0.1343	0.0193	0.0018	0.0017	0.0222	0.0099	0.0045	0.0151	0.0261
27. Hii et al.	$MR = a\exp(-bt^c) + d\exp(-gt^c)$									
	a	2.1414	7.7404	1.6440	7.0855	22.5891	3.7026	3.7856	19.6368	
	b	0.1856	0.0786	0.0180	0.0916	0.0320	0.0053	0.0363	0.0676	
	c	0.3894	0.5898	0.8191	0.6243	0.6523	0.9073	0.6672	0.6401	
	d	-1.1455	-6.7433	-0.6458	-6.0872	-21.578	-2.6961	-2.7875	-18.6315	
	g	0.5414	0.0922	0.0351	0.1074	0.0333	0.0059	0.0487	0.0710	
	R^2	0.9929	0.9984	0.9982	0.9971	0.9984	0.9990	0.9998	0.9975	0.997662
	RMSE	0.0172	0.0099	0.0106	0.0127	0.0100	0.0084	0.0033	0.0119	0.0105
	SSE	0.0312	0.0103	0.0059	0.0083	0.0105	0.0074	0.0011	0.0150	0.011212
28. Weibull-I	$MR = a - b\exp(-kt^n)$									
	a	0.0723	0.0139	0.0190	0.0199	-0.0186	-0.0267	0.0116	0.0130	
	b	-0.9805	-1.0192	-0.9686	-0.9814	-1.0506	-1.0429	-1.0022	-0.9972	
	k	0.0154	0.0062	0.0035	0.0077	0.0048	0.0044	0.0038	0.0072	
	n	0.7555	0.9181	1.0724	0.9851	0.8420	0.8947	0.9519	0.9315	
	R^2	0.9907	0.9979	0.9996	0.9996	0.9988	0.9993	0.9997	0.9979	0.997937

	RMSE	0.0197	0.0112	0.0050	0.0048	0.0088	0.0068	0.0048	0.0109	0.009
	SSE	0.0410	0.0134	0.0013	0.0012	0.0083	0.0050	0.0024	0.0126	0.01065
29. Weibull-III	$MR = \exp\left[-\left(\frac{t}{b}\right)^{a}\right]$									
	a	0.6412	0.9168	0.9949	0.9274	0.9044	0.9587	0.9439	0.9081	
	b	341.873	275.675	201.954	146.439	570.901	417.219	362.519	209.066	
	R^2	0.9792	0.9967	0.9979	0.9964	0.9984	0.9989	0.9993	0.9972	0.9955
	RMSE	0.0291	0.0139	0.0113	0.0138	0.0100	0.0087	0.0065	0.0125	0.013225
	SSE	0.0916	0.0210	0.0070	0.0104	0.0108	0.0081	0.0046	0.0168	0.021287
30. Jena and Das	$MR = a\exp\left(-kt + bt^{\frac{1}{2}}\right) + c$									
	a	0.9767	1.0131	0.9729	0.9818	1.0386	1.0383	0.9963	1.0017	
	b	-0.0291	-0.0077	0.0070	-0.0024	-0.0111	-0.0086	-0.0034	-0.0096	
	c	0.0824	0.0185	0.0164	0.0201	0.0002	-0.0150	0.0167	0.0153	
	k	0.0022	0.0034	0.0056	0.0070	0.0013	0.0019	0.0027	0.0044	
	R^2	0.9880	0.9976	0.9994	0.9996	0.9982	0.9992	0.9996	0.9979	0.997437
	RMSE	0.0223	0.0121	0.0062	0.0048	0.0107	0.0075	0.0053	0.0110	0.009987
	SSE	0.0527	0.0154	0.0020	0.0012	0.0121	0.0060	0.0030	0.0128	0.01315
31. Haghi and Angiz-I	$MR = a\exp(-bt^{c}) + dt^2 + et + f$									
	a	0.7148	0.5145	0.9914	1.0291	0.4196	0.3466	0.6703	0.7775	
	b	0.0024	0.0014	0.0039	0.0088	0.0009	0.0021	0.0023	0.0100	

	c	1.1518	1.3255	1.0442	0.9478	1.2626	1.2001	1.1031	0.9083	
	d	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	e	-0.0001	-0.0008	0.0000	0.0001	-0.0005	-0.0008	-0.0004	-0.0005	
	f	0.2730	0.4841	0.0004	-0.0230	0.5735	0.6524	0.3250	0.2423	
	R^2	0.9994	0.9994	0.9997	0.9998	0.9998	0.9999	0.9999	0.9988	0.999587
	RMSE	0.0048	0.0058	0.0042	0.0037	0.0031	0.0028	0.0021	0.0085	0.004375
	SSE	0.0025	0.0035	0.0009	0.0007	0.0010	0.0008	0.0005	0.0075	0.002175
32. Haghi and Angiz-III	$MR = \frac{a+bt}{1+ct+dt^2}$									
	a	1.0000	1.0216	0.9772	0.9893	1.0000	1.0056	1.0036	1.0019	
	b	82.0610	-0.0005	-0.0006	-0.0003	180.133	-0.0006	-0.0005	-0.0007	
	c	73.5601	0.0035	0.0027	0.0052	148.341	0.0021	0.0023	0.0044	
	d	0.5022	0.0000	0.0000	0.0000	0.7180	0.0000	0.0000	0.0000	
	R^2	0.9939	0.9980	0.9980	0.9973	0.9527	0.9993	0.9999	0.9970	0.992012
	RMSE	0.0159	0.0108	0.0110	0.0121	0.0549	0.0071	0.0028	0.0131	0.015962
	SSE	0.0268	0.0123	0.0065	0.0078	0.3199	0.0053	0.0008	0.0182	0.0497
33. Sripinyowanich and Noomhorm	$MR = \exp(-kt^n) + bt + c$									
	b	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	c	0.1058	0.0284	-0.0071	0.0052	0.0332	0.0118	0.0179	-0.0024	
	k	0.0201	0.0058	0.0040	0.0085	0.0047	0.0041	0.0040	0.0066	
	n	0.7266	0.9328	1.0379	0.9610	0.8531	0.9129	0.9462	0.9421	

	R^2	0.9912	0.9979	0.9997	0.9997	0.9989	0.9993	0.9997	0.9980	0.99805
	RMSE	0.0191	0.0113	0.0041	0.0039	0.0084	0.0070	0.0047	0.0106	0.008637
	SSE	0.0387	0.0135	0.0009	0.0008	0.0075	0.0053	0.0023	0.0119	0.010112
34. Noomhorm and Verma	$\mathrm{MR} = \mathrm{a} \exp(-kt) + b \exp(-gt) + c$									
	a	0.7039	0.2749	8.18×10^{-5}	0.0349	0.8087	0.0224	0.9770	0.1109	
	b	0.3186	0.7456	0.9953	0.9482	0.2090	0.9775	0.0028	0.8915	
	c	0.0000	0.0103	0.0140	0.0198	0.0000	3.54×10^{-7}	0.0204	0.0139	
	g	0.0008	0.0031	0.0052	0.0070	0.0053	0.0023	0.8527	0.0045	
	k	0.0060	0.0081	0.6554	0.0224	0.0014	1.0125	0.0029	0.0196	
	R^2	0.9978	0.9982	0.9991	0.9996	0.9990	0.9987	0.9995	0.9982	0.998762
	RMSE	0.0095	0.0103	0.0074	0.0047	0.0081	0.0095	0.0057	0.0103	0.008187
	SSE	0.0096	0.0112	0.0028	0.0011	0.0069	0.0095	0.0035	0.0111	0.006962
35. Hasibuan and Daud	$\mathrm{MR} = 1 - \mathrm{a}\, t^n \exp(-kt^m)$									
	a	1.5021	0.8850	0.5932	757.943	0.1285	0.0139	0.0255	0.0129	
	k	5.9144	7.0298	6.2848	12.0885	5.6650	3.0820	3.9449	1.7184	
	m	0.1280	0.1400	0.1499	0.1086	0.1388	0.1767	0.1704	0.2233	
	n	1.9938	2.6890	2.6357	2.7441	2.4051	2.1154	2.3734	1.7895	
	R^2	0.9886	0.9984	0.9981	0.9953	0.9992	0.9995	0.9996	0.9989	0.9972
	RMSE	0.0218	0.0097	0.0108	0.0161	0.0073	0.0059	0.0049	0.0079	0.01055
	SSE	0.0504	0.0099	0.0061	0.0137	0.0057	0.0037	0.0025	0.0066	0.012325

36. Henderson and Henderson-I	$MR = c\left[\exp(-kt) + \frac{1}{9}\exp(-9kt)\right]$									
	c	0.7782	0.9331	0.9430	0.9234	0.9176	0.9367	0.9376	0.9201	
	k	0.0019	0.0033	0.0047	0.0062	0.0016	0.0022	0.0026	0.0043	
	R^2	0.9345	0.9957	0.9963	0.9955	0.9979	0.9988	0.9986	0.9967	0.98925
	RMSE	0.0517	0.0159	0.0149	0.0154	0.0114	0.0089	0.0094	0.0136	0.01765
	SSE	0.2891	0.0273	0.0122	0.0130	0.0140	0.0086	0.0096	0.0201	0.049237
37. Henderson and Henderson-II	$MR = c\exp(-kt) + \frac{1}{9}\exp(-9kt)$									
	c	0.7584	0.9297	0.9414	0.9194	0.9134	0.9343	0.9351	0.9159	
	k	0.0019	0.0033	0.0047	0.0062	0.0016	0.0022	0.0026	0.0043	
	R^2	0.9384	0.9957	0.9961	0.9954	0.9980	0.9987	0.9985	0.9967	0.989687
	RMSE	0.0502	0.0159	0.0153	0.0155	0.0113	0.0092	0.0097	0.0136	0.017587
	SSE	0.2718	0.0273	0.0128	0.0133	0.0138	0.0092	0.0101	0.0200	0.047287
38. Logistic	$MR = a_0/[1 + a\exp(kt)]$									
	a	$1.6\times10^{+4}$	$6.6\times10^{+3}$	115.8015	$2.9\times10^{+3}$	$1.2\times10^{+3}$	843.0767	$1.467\times10^{+3}$	$4.229\times10^{+3}$	
	a_0	$1.3\times10^{+4}$	$6.5\times10^{+3}$	116.6626	$2.8\times10^{+3}$	$1.1\times10^{+3}$	827.4701	$1.442\times10^{+3}$	$4.084\times10^{+3}$	
	k	0.0020	0.0035	0.0050	0.0066	0.0016	0.0023	0.0027	0.0045	
	R^2	0.9200	0.9946	0.9979	0.9953	0.9960	0.9986	0.9984	0.9953	0.987012
	RMSE	0.0574	0.0179	0.0115	0.0158	0.0158	0.0097	0.0101	0.0163	0.019312
	SSE	0.3530	0.0343	0.0071	0.0135	0.0268	0.0100	0.0110	0.0284	0.060512

39. Aghbashlo	$MR = \exp\left(-\frac{k_1 t}{1+k_2 t}\right)$									
	k_1	0.0044	0.0040	0.0051	0.0075	0.0019	0.0025	0.0029	0.0052	
	k_2	0.0012	0.0003	0.0001	0.0005	0.0001	0.0001	0.0001	0.0004	
	R^2	0.9945	0.9977	0.9980	0.9974	0.9981	0.9985	0.9997	0.9975	0.997675
	RMSE	0.0150	0.0115	0.0110	0.0118	0.0110	0.0099	0.0041	0.0118	0.010762
	SSE	0.0243	0.0143	0.0067	0.0077	0.0131	0.0105	0.0018	0.0151	0.011687
40. Three-parameter model	$MR = a\exp[-(kt)^n]$									
	a	1.0991	1.0458	1.0026	1.0142	1.0218	1.0001	1.0222	1.0236	
	k	0.0035	0.0039	0.0050	0.0070	0.0018	0.0024	0.0028	0.0049	
	n	0.5888	0.8711	0.9916	0.9123	0.8807	0.9586	0.9186	0.8834	
	R^2	0.9829	0.9974	0.9979	0.9965	0.9986	0.9989	0.9995	0.9974	0.996137
	RMSE	0.0265	0.0124	0.0114	0.0137	0.0094	0.0087	0.0055	0.0121	0.012462
	SSE	0.0752	0.0164	0.0070	0.0102	0.0095	0.0081	0.0033	0.0156	0.018162
41. Asymptotic model	$MR = a_0 + a\exp(-kt)$									
	a	0.8629	0.9785	0.9954	0.9758	0.9549	0.9805	0.9773	0.9637	
	a_0	0.0975	0.0225	0.0140	0.0206	0.0211	0.0000	0.0204	0.0193	
	k	0.0036	0.0038	0.0052	0.0071	0.0018	0.0023	0.0029	0.0049	
	R^2	0.9837	0.9973	0.9991	0.9996	0.9970	0.9986	0.9995	0.9975	0.996537
	RMSE	0.0259	0.0127	0.0072	0.0048	0.0138	0.0097	0.0057	0.0119	0.011462
	SSE	0.0718	0.0173	0.0028	0.0013	0.0203	0.0100	0.0035	0.0151	0.017762

42. Khazaei and Daneshmandi	$MR = a + \exp(-bt) - ct$									
	a	0.1818	0.0095	-0.0036	0.0072	-0.0226	-0.0195	-0.0004	-0.0204	
	b	0.0057	0.0038	0.0050	0.0070	0.0017	0.0023	0.0028	0.0046	
	c	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	R^2	0.9713	0.9970	0.9994	0.9994	0.9963	0.9985	0.9993	0.9974	0.994825
	RMSE	0.0344	0.0134	0.0059	0.0058	0.0152	0.0100	0.0066	0.0121	0.012925
	SSE	0.1266	0.0191	0.0019	0.0018	0.0248	0.0107	0.0047	0.0158	0.025675
43. Sigmoid	$MR = a + \frac{b}{1+e^{k(t-c)}}$									
	a	0.1108	0.0368	0.0264	0.0281	0.0496	0.0121	0.0463	0.0313	
	b	1.2832	1.8149	1.8684	1.8328	1.7551	9.8226	1.8052	1.7676	
	c	80.0000	0.0000	0.0000	0.0000	0.0002	-899.995	0.0000	0.0000	
	k	0.0058	0.0054	0.0073	0.0099	0.0026	0.0025	0.0042	0.0067	
	R^2	0.9665	0.9906	0.9984	0.9953	0.9897	0.9978	0.9955	0.9918	0.9907
	RMSE	0.0373	0.0237	0.0100	0.0161	0.0256	0.0121	0.0172	0.0217	0.020462
	SSE	0.1478	0.0596	0.0053	0.0137	0.0694	0.0155	0.0313	0.0499	0.049062

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