THIN LAYER DRYING KINETICS, MODELLING AND OPTIMIZATION OF PROCESS CONDITIONS FOR BLUE WHITING FISH (MICROMESISTIUS POUTASSOU) SLICES USING RESPONSE SURFACE METHODOLOGY (RSM)

BY

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26th January, 2022.

The Project Coordinator

Department of Chemical Engineering,

Obafemi Awolowo University,

Ile Ife, Osun State.

Dear Sir,

LETTER OF TRANSMITTAL

Having completed the laboratory requirements for the research work, I hereby submit this thesis as a partial fulfilment of the requirements for the award of Bachelor of Science degree (B.Sc.) in Chemical Engineering, Obafemi Awolowo University.

This report contains detailed experimental work and results of the experimental study carried out. Thank you in anticipation for your consideration and acceptance of the report.

Yours faithfully,

THOMPSON-AJAYI Busayomi David.

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CHE/2015/093

CERTIFICATION

This is to certify that the research work titled: *Thin Layer Drying Kinetics, Modelling And Optimization Of Process Conditions For Blue Whiting Fish (Micromesistius Poutassou) Slices Using Response Surface Methodology (RSM)* was carried out by Thompson-Ajayi, Busayomi David, with matriculation number CHE/2015/093, under my supervision.

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Dr. O. Sanda Date

(Supervisor)

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Dr. O. Sanda Date

(Supervisor)

DEDICATION

This thesis is dedicated to all students of Chemical Engineering across various institutions in Nigeria that aspire to achieve immeasurable and immense success in various fields of Chemical Engineering and make the world a better and safer place for all humans.

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My heartfelt gratitude goes to my ever-supportive Supervisor, Dr. O. Sanda, for taking his precious time to ensure this research work was brought to fruition. I am deeply grateful for all your guidance sir. You, sir, have been impacted my life positively in many ways. God bless you abundantly.

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ABSTRACT

The drying process of Blue Whiting fish fillets was investigated in a laboratory-scale dryer. Drying experiments were conducted at five temperatures of 60˚C, 70˚C, 80˚C, 90˚C, and 100˚C. The experimental data were fitted to three different thin-layer drying models to select a suitable model for describing the drying process of Blue Whiting fish. The models were compared using the coefficient of determination (R^2) and the root mean square error (RMSE). At 60 ˚C, the Logarithmic model best represented the drying curve while the Page model best fit the experimental data at the remaining experimental temperatures.

Correlation between the model parameters and the drying air temperature (under hot air drying) to calculate moisture ratio in relation to the drying time were also determined. The transport of water during drying was described by application of Fick's diffusion model and the effective moisture diffusivity was estimated.

It was also observed that the sample thickness, drying temperature, drying time, brine, and acid concentration significantly affected the sample's moisture content and shelf life. The moisture content was then quantitatively investigated during the drying process using Response Surface Methodology (RSM). The independent process variables for the drying process were Drying Time (135-195 min), Drying Temperature ($65\text{-}85^0$c), Salt Concentration (3-7 %), and Acid Concentration (1-5 %). A two-factorial interaction (2FI) regression model describing the effects of these variables on the moisture content was developed. Drying Temperature had the strongest effect on the moisture content while the acid concentration had the least. The optimum conditions were found to be at Drying Time = 184.74 min; Drying Temperature = 80.24^0c; Salt

Concentration = 6.04%; Acid Concentration = 2.26%. At these conditions, the moisture content was 3.115%.

CHAPTER ONE

INTRODUCTION

1.1 Project Overview

The world population is growing drastically, and thus, food demand has been increasing likewise. The awareness of the benefits of consuming nutritious food has made the demand for particular nutritious foodstuffs, such as fish, rank at the top of the highly demanded foodstuffs in this modern era. According to FAO (2016), global seafood consumption has increased dramatically from 9.9kg per capita in the 1960s to 20 kilograms in 2016. In addition to this, the exports of fishery products in developing countries deposited an income of $80 billion annually and were estimated to be $148 billion on world scale exports in 2014.

Fish is a vital food resource for humans worldwide and has been a food source for man since the dawn of time. It is the perfect blend of taste, versatility, and nutrients. Fish protein can be characterized as complete and contain essential amino acids and necessary quantities to meet the body's needs. In addition, fish is a source of vitamins, especially Vitamins K, E, D, and A, which are very good for the body. Fish is also a rich source of minerals like sodium, potassium, sulphur, and iron. Although saltwater fish are richer in minerals than freshwater fish, as iodine is not found in freshwater fish, it is present in a large percentage of saltwater fish (Hassan, *et al*, 1985).

However, fish is also known for its high perishability nature. With moisture content ranging from 65 to 81%, one problem is commonly encountered when handling fish which is spoilage. The spoilage mechanisms associated with such deteriorations are grouped into microbial metabolic activities, endogenous enzymatic activities, and chemical oxidation of lipids, all of which shorten the shelf life of seafood. The high content of non–protein nitrogen compounds and low acidity (pH>6) of seafood meat, according to Gram and Huss (1996), are the primary causes of spoilage, as these conditions promote the proliferation of spoilage microbes. These microorganisms create compounds, which alter the seafood's organoleptic qualities and render it unfit for ingestion.Similarly, autolytic activities by endogenous enzymes of seafoods also results in loss of its characteristic odour and taste; and then softens the flesh. These changes start shortly after the death of seafood animals and produce several volatile compounds that give the products their spoilage characteristics. According to Fellows and Hamptum (1992), for context, most fish become inedible within 12 hours of catching at tropical temperatures. Microbial metabolic activities often accompany these enzyme-driven changes. Finally, chemical oxidation of lipids is a common spoilage pattern in fatty fish. This rotting pattern is primarily determined by the presence of oxygen, which causes oxidative rancidity in polyunsaturated fatty acids found in fish and fishery products (Ashie, et al., 1996). Despite the fact that the rotting patterns of fish may be divided into three groups, all of the processes operate at the same time, speeding up the overall spoilage of the fishs. As previously stated, the spoilage mechanisms can be driven by microbial growth, enzymatic activities or chemical reactions and refrigeration does little to stifle these bacteria as they are psychrophilic in nature, i.e.,

capable of growth and reproduction at very low temperatures (-20 to +10^{o}C); hence preservation methods targeted at these three causes are required.

Food preservation methods such as smoking, frying, and excessive salting pose serious health and environmental concerns, as opposed to drying, which is an efficient preservation method. Drying, however, allows for the retention of fish's nutritive and sensory quality while greatly extending its safe storage life (Shitanda & Wanjala, 2006). Sun drying, air drying, hot air drying, solar drying, oven drying, microwave drying, freeze drying, spray drying, vacuum drying, osmotic drying, and other drying techniques have all been used in food preservation. (Sagar and Kumar, 2010).

Drying is a complicated process as it involves simultaneous transfer of heat and mass. Therefore, thin-layer drying models for describing the drying process in fish are usually based on liquid diffusion theory. This process can be explained by the Fick's second law.

1.2 Statement of Research Problem

Globally, 10-12 million tonnes of fish are lost annually to spoilage and about 20 million tonnes of fish are discarded at sea. This spoilage is one of the major causes of post-harvest fish loss faced by fishermen. These losses lead to increased level of poverty amongst fishermen. Nigeria is no exception to this. With a land area of approximately 930,000 km^2 and possessing about 14 million hectares of inland waters, Nigeria has one of the highest fish yields per area within West Africa. Consumption however is one of the lowest due to post harvest losses. Annual fish demand in Nigeria is estimated at 3.32 million metric tonnes —an unsurprisingly high number considering Nigeria's population of about 190

million people (FCWC, 2016). However, annual domestic fish production in Nigeria is about 1.12 million metric tonnes. This leaves a deficit of 2.2 million metric tonnes, which is largely supplied through importation. Ideally, this should not be happening as Nigeria has the resources and potential for a fish industry that can meet its consumption demands.

In Nigeria, Artisanal Fishing dominates the fishing sector, accounting for about 80 percent of Nigeria's total fish production. However, this crude, low-capital fishing practice is often accompanied by poor handling and processing of the harvested fish, which leads to high level of quantity and quality loss of fishery products.

1.3 Aim and Objectives

The aim of the study is to dry blue whiting (panla) treated with salt and propionic acid in a convection oven. The specific objectives of this study are to:

a. Treat blue whiting fillets with preservatives such as salt and propionic acid prior to drying;

b. To investigate the drying characteristics and kinetics of blue whiting fish fillets of constant thickness under forced convection drying using an oven

c. To optimize the processing conditions by using the Response Surface Methodology (RSM).

CHAPTER TWO

LITERATURE REVIEW

2.1 Blue Whiting Fish

Micromesistius poutassou, the blue whiting, is a common fish found in the northeast Atlantic Ocean, from Morocco to Iceland and Spitsbergen. It is one of two species in the cod family's Micromesistius genus. It has a long, slender body with a silvery underbelly (Bailey, 1982). The fish can reach a length of more than 40 cm. Blue whiting fish is a rich source of vitamin B, magnesium, and protein..

As shown in Table 2.1, each 100-gram serving of Blue Whiting (the size of a standard filet) is 75 kilocalories and contains roughly 1 grams of protein with about 1 gram of fat. This high protein and low-fat content make it a healthy lean protein food choice (FAO, 2005). Table 2.2 highlights the water and fat content of fillets Blue Whiting compared to other fish species.

Mature blue whiting is usually found in the open sea, near the surface or in mid-water, but can also be found at depths of up to 1,000 metres. The Blue whiting fish is highly migratory, but at irregular times of the year.

Table 2.1: Nutritional Value of *Micromesistius poutassou.*

Principle	**Nutrient Value**	**Percentage of RDA**
Energy	78Kcal	4%
Carbohydrates	0g	0%
Protein	17.54g	31%
Total Fat	0.88g	4.4%
Cholesterol	20mg	10%
Dietary Fiber	0g	0%
Vitamin-A	0 IU	0%
Vitamin-C	1.1 mg	2%
Electrolytes		
Sodium	100mg	6.5%
Minerals		
Calcium	44mg	<1%
Iron	0.95mg	2%

Note: Data from Poulter and Nicolaides (1985)

Table 2.2: Water and fat content of fillets of various fish species relative to Blue Whiting

Species	**Scientific Name**	**Water (%)**	**Lipid (%)**
Blue Whiting	*Micromesistius poutassou*	79.0–80.0	1.9–3.0
Cod	*Gadus morhua*	78.0–83.0	0.1–0.9
Eel	*Anguilla anguilla*	60.0–71.0	8.0–31.0
Herring	*Clupea harengus*	60.0–80.0	0.4–22.0
Plaice	*Pleuronectes platessa*	81.0	1.1–3.6
Salmon	*Salmo salar*	67.0–77.0	0.3–14.0
Corvina	*Plagioscion squamosissimus*	67.9	5.9
Carp	*Cyprinus carpio*	81.6	2.1
Tuna	*Thunnus spp*	71.0	4.1
Bagre	*Ageneiosus spp.*	79.0	3.7
Trout	*Salmo trutta*	70.0–79.0	1.2–10.8

Note: Data from Murray and Burt (1969), and Poulter and Nicolaides (1985)

2.2 Spoilage in Fish

The two attributes that must be clearly stated are spoilage and freshness (Gram and Huss, 2000). A fresh product is one whose original characteristics have not changed. As a result, spotting is a sign of post-harvest alteration (Hui, 2006). This change can be rated as a progression from absolute freshness to acceptable limits to unacceptable levels. Spoilage in fish is typically accompanied by changes in physical qualities, such as colour, odour, texture, and softness (Baird-Parker, 2000).

The action of enzymes, bacteria, and chemicals found in the fish causes spoilage. Figure 2.1 shows the process of spoilage in Fish. The following factors contribute to seafood spoilage: (Abbas and Saleh, 2009)

- High moisture content
- High fat content
- High protein content
- Unhygienic handling

2.2.1 Process of Spoilage

Fish is highly nutritious. It is tasty because of its constituents. The main components of fish are water, protein, and fat (Adebowale et al., 2008). The deterioration of fish is a sophisticated process involving enzymes, microorganisms, and chemical elements. After a fish dies, the rotting process begins instantly.The process involves three stages (Amos, 2007).

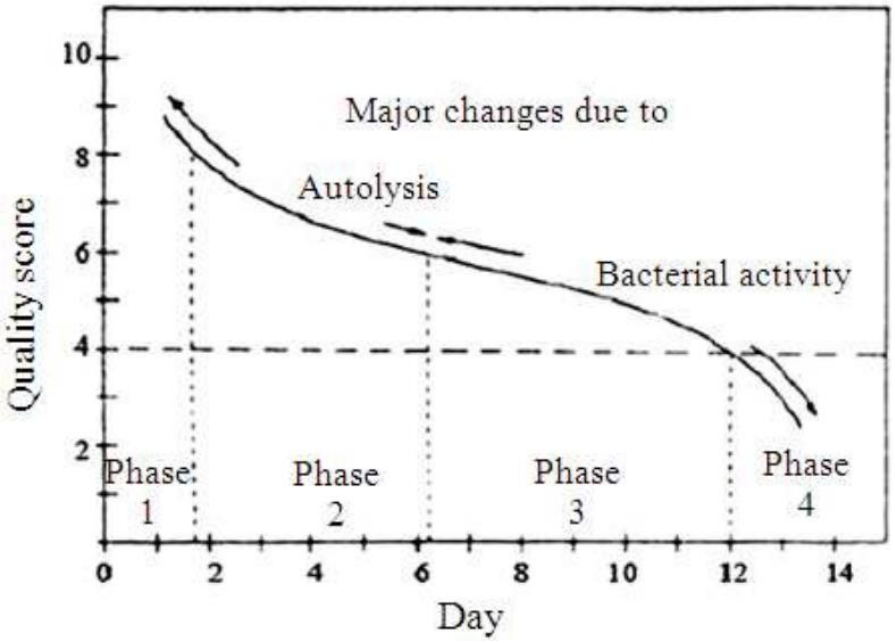


Figure 2.1: Chart showing stages of spoilage in fish.

a. Enzymatic spoilage

Shortly after fish is captured, Biological and Chemical changes occur in the dead fish due to the enzymatic breakdown of major fish molecules (FAO, 2005). According to Hansen et al. (2003), autolytic enzymes reduce textural quality during early stages of deterioration but do not produce the characteristic spoilage off-odors and off-flavors. This indicates that enzymatic degradation can limit shelf-life and product quality even with relatively low levels of visible spoilage (FAO, 2005). The major effect of this kind of spoilage is on textural quality and the production of hypoxanthine and formaldehyde.

Several proteolytic enzymes are usually found in the muscle and viscera of the fish after the catch. These enzymes contribute to post-mortem degradation in fish products during storage and processing.

b. Microbial spoilage

The composition of the microflora on newly caught fish is dependent on the microbial contents of its habitat. Bacterial fish microflora includes species such as Pseudomonas, Micrococcus, Vibrio and Alcaligenes (Gram and Huss, 2000). Microbial growth and metabolism are major causes of spoilage in fish. It leads to the production of amines, biogenic amines such as putrescine, histamine and cadaverine, organic acids, sulphides, alcohols, aldehydes, and ketones with unpleasant and unacceptable off-flavors. For unpreserved fish, spoilage is a result of Gram-negative, fermentative bacteria (such as

Vibrionaceae), whereas psychrotolerant Gram-negative bacteria (such as Pseudomonas spp. and Shewanella spp.) tend to spoil chilled fish (Gram and Huss, 2000).

c. Chemical spoilage

Lipid oxidation is a major cause of deterioration and spoilage for pelagic fish species such as mackerel and herring with high oil/fat content stored fat in their flesh (Fraser and Sumar, 2008). Lipid oxidation involves a three-stage free radical mechanism: initiation, propagation and termination (Khayat and Schwall, 2003; Frankel, 2005).

Initiation involves the formation of lipid free radicals through catalysts such as heat, metal ions and irradiation. These free radicals react with oxygen to form peroxyl radicals.

Peroxyl radicals combine with other lipid molecules to create hydroperoxides and a new free radical during propagation (Hultin, 2004; Fraser and Sumar, 2008). When a buildup of these free radicals interacts to generate non-radical products, termination happens. The reaction of oxygen with the double bonds of fatty acids is known as oxidation. As a result, polyunsaturated fatty acids in fish lipids are especially vulnerable to oxidation. To allow oxidation to take place, molecular oxygen must be activated. Transition metals are the principal molecular oxygen activators (Hultin, 2004). Lipid oxidation can happen enzymatically or non-enzymatically in fish. Lipolysis is the enzymatic degradation of fats by lipases (fat

deterioration).During this process, lipases split the glycerides forming free fatty acids which are responsible for common off flavour, frequently referred to as rancidity, and reduction in the oil quality (Huis in't Veld, 2006; FAO, 2005).

In order to mitigate spoilage in fish, steps must be taken to preserve the fish after harvest.

2.3 Food Preservation via Salting and Drying

2.3.1 Salting

Food preservation through the use of salt has been practiced since the dawn of time. The concept has not changed, even though it has been developed throughout time. This strategy uses two methods to keep food fresh:

a. Salt draws water from food, dehydrating it. As a result, the growth of these mirobes is inhibited since all living things, including bacteria that cause food rotting, require water, and cannot thrive without it (Koo, 2020).
b. Salt kills microbes. The impact of osmolarity, or water pressure, makes high salt concentration harmful to most (but not all) germs. Water diffuses between cells in the environment so that the concentration of solutes (such as salt) is the same on both sides of the cell. Many microbes will rupture in very high salt solutions due to the pressure difference between the outside and inside of the organism. High salt levels can also be hazardous to microorganisms' internal functions, damaging DNA and enzymes. (Koo, 2020).

2.3.2 Drying

Drying is the act of removing moisture from a sample while simultaneously transferring heat and mass under controlled conditions (Brooker et al., 1992; Akpinar, *et al.*, Yaldiz, 2003; Ertekin and Yaldiz, 2004). Drying removes moisture from fish, which in turn arrests microbial activity. It also slows the action of enzymes but does not render them inactive. Drying improves the overall quality of harvested fish and makes it easier to handle in addition to serving as a preservative. However, if the drying process is not done properly, i.e., if the drying is done too quickly, layer hardening (hard texture) can occur, which negatively affects the product's palatability. If the drying process is delayed, however, unwanted microorganisms may survive and thrive.

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

In drying fish, convective drying in hot air is still the most popular method applied to reduce moisture content. However, the downsides of convective drying in hot air are: very

long drying period, high-energy consumption, contamination problems,and high costs, which are undesirable for the food industry. But, the desire to reduce these problems and achieve a fast and relatively effective thermal process led to the use of microwave ovens and dielectric heating methods for drying. These drying methods have several advantages like a higher drying rate, shorter drying time, decreased energy consumption, and better quality of the products compared with convective drying in hot air.

Drying is the most energy-intensive in the food sector. As a result, improving drying operations by lowering energy consumption, boosting process efficiency, and producing high-quality goods with little economic input has become the primary objective of modern drying. A flow diagram showing the drying process in a tunnel dryer is represented in Figure 2.2

Three types of drying are used for fish preservation, namely, air or contact drying, vacuum drying and freeze-drying.

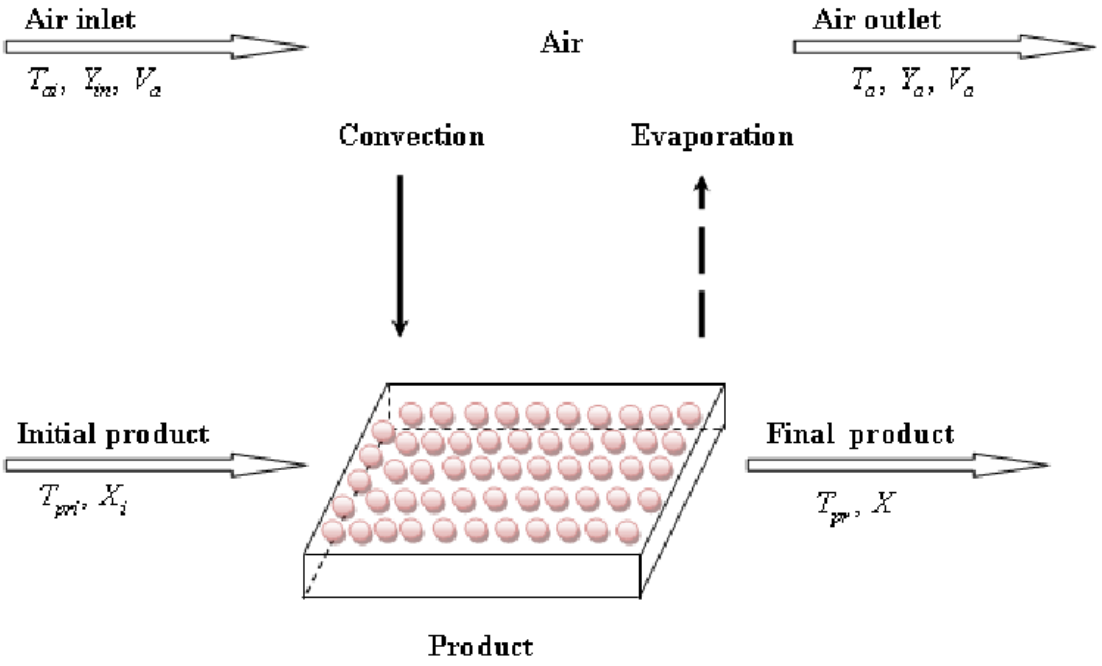


Figure 2.2: Flow diagram of drying process in a tunnel dryer (Ouslati et al. 2012)

2.4 Drying Kinetics

Drying moist materials is a complicated process that includes simultaneous heat and mass transfer. Thin-layer drying models for describing agricultural products' drying phenomenon are usually based on liquid diffusion theory, and the process can be explained by the Fick's second law (Doungporn, *et al.*, 2012). The thin-layer drying models can be categorised as either theoretical, semi-theoretical or empirical models. Different researchers have investigated the drying characteristics or behavior of different food materials including fruit and vegetables, seafood products using different drying methods such as open sun drying for grapes (Togrul and Pehlivan, 2004), fish (Jain and Pathare, 2007), and onion slices (Arslan and Ozcan, 2010); solar drying for green pepper (Akpinar, *et al.*, 2003), strawberry (El-Beltagy et al., 2007), tomato (Doymaz, 2008), and carrot (Zielinska and Markowski, 2010), respectively. The drying characteristic curves of most of these food materials were modeled using different drying models such as the Newton model (Menzies and O'Callaghan, 1971), Page model (Akpinar et al., 2003), Henderson and Pabis model (Karathanos and Belessiotis, 1999), logarithmic model (Yaldiz, *et al.*, 2001), two-term exponential model (Akpinar, *et al.*, 2003). The studies based on simulation models are needed for the design and operation of dryers and useful in improving the existing drying technology.

2.5 Multivariate Analysis

Multivariate analysis is a statistical method that measures relationships between two or more response variables (Jackson, 2018). Multivariate techniques allow researchers to look at relationships between variables in an overarching way and to quantify the relationship between variables, by attempting to model reality where each situation, product, or decision involves more than a single factor. Multivariate techniques control the association between variables by using cross-tabulation, partial correlation and multiple regressions and introduce other variables to determine the links between the dependent and independent variables or specify the conditions under which the association occurs. Thus, multivariate analysis in a broader scope allows the researcher to collect a more realistic picture than looking at a single variable. Response Surface Methodology (RSM) is a multivariate statistical tool and offers a new approach to investigate drying processes. RSM provides better result reproducibility and process optimization with a nuanced perspective for predictive model development. (Jackson, 2018)

A response surface design is a collection of advanced design of experiments (DOE) approaches that aid in the understanding and optimization of your response. Response surface design methodology is often used to refine models after determining important factors using screening designs or factorial designs; especially if curvature in the response surface is suspected.

Response surface methodology (RSM) is a technique for optimizing a process that includes sophisticated calculations. This method creates an appropriate experimental design that

incorporates all of the independent variables and uses the data input from the experiment to generate a set of equations that can calculate the theoretical value of an output. The results are based on the controlled values of independent variables and come from a well-designed regression study.

In a collection of experimental designs, one element or process variable can depend on or be dependent on another variable. In order to determine the output-input relationship, it is necessary to understand how the elements interact. This is why one-factor-at-a-time approaches are rarely used to determine interactions. (Ikrang, et al. 2014)

CHAPTER THREE

METHODOLOGY

3.1 Materials Used

The fish samples (blue whiting) was purchased from a cold room in Ile-Ife, Nigeria, while the table salt (sodium chloride) and the preservative (propionic acid) were purchased from a confectionery store in OAU Central Market, Obafemi Awolowo University, Ile Ife. Other materials and apparatus (such as oven, knives set, cutting board, washing bowls) were provided for use in the Laboratory. All washings were done using pre-chlorinated tap water.

3.2 Experimental Procedure

This experimental procedure is divided into two parts, which are, drying kinetics analysis and the optimization studies. For both experiments, samples were obtained from the same source to ensure homogeneity and minimize errors.

The fish sample was washed in preparation for cutting to fillets. Prior filleting, the fish was gutted. This process involves making a cut across the fish at an angle, below the gill flap, down to the belly. After removing the head and gutting, the fish was cut longitudinally into two halves and the bone removed. The fillets obtained were cut into sizes of thickness 7mm.

After cutting out these relatively similar-sized fillets, 50g of the fillets was weighed out and placed onto a foil-covered platform. This sample was placed into the preheated oven to dry. The change in weight of the sample was measured at 10 minute intervals, and the drying rate was monitored. The sample was dried until negligible weight drop was observed at intervals. The sample weight at all intervals was recorded and used to determine the sample's moisture content at each point during the experiment. This served as the basis for developing the parameters used for Multivariate analysis. This process was repeated for each run at constant sample weight but at different drying temperatures.

3.2.1 Moisture Content Determination

The data obtained from the experiments were transformed into dimensionless parameter, known as moisture contents, which was usually expressed as

$$Mt = \frac{Wf - Wd}{Wd} \quad 3.1$$

Where:

Mt = Moisture content of the sample (dry basis), %

W_f = Weight of fresh sample, g.

W_d = Weight of oven-dried sample, g.

3.2.2 Moisture Ratio Determination

The moisture content obtained from the experiments is used to determine the moisture ratio, this is expressed in equation 3.2.

$$M.R = \frac{Mt-Me}{Mo-Me} \quad 3.2$$

However, this could be simplified to the expression shown in equation 3.3

$$M.R = \frac{Mt}{Mo} \quad 3.3$$

Where:

MR represents moisture ratio, dimensionless

Mt represents the moisture content of the product after drying time t

Me represents the stable or equilibrium moisture content of the product

Mo represents the initial moisture content of the sample

3.2.3 Determination of effective moisture diffusivities

Fick's diffusion equation, which may be used to characterize the drying characteristics of biological products in a falling rate period, can be used to calculate the effective moisture diffusivity. It can be simplified for a long drying period (Tutuncu and Labuza 1996) as follows:

$$lnMR = \frac{8}{\pi^2} - \frac{\pi^2 D_{eff} t}{4Lo^2} \quad 3.3$$

Where,

D_{eff} is the effective moisture diffusivity (m^2 /s),

L_0 is the half-thickness of slab (m).

The effective moisture diffusivity was calculated using the method of slopes. It is typically determined by plotting experimental drying data in terms of ln(MR) versus time (Lomauro, Bakshi and Labuza 1985,). From Eq. (3), a plot of ln(MR) versus time gives a straight line with slope:

$$Slope = -\frac{\pi^2 D_{eff} t}{4Lo^2}$$

3.2.4 Drying Constant Determination

The obtained drying curves were processed to find the most convenient one among 5 different expressions defining drying rates given in table 3.1 by several authors. The drying constants would then be determined.

3.2.5 Model Validation

Graphical and statistical analyses were used in validating the three tested drying models. Graphical validation was done by comparing the predicted moisture content with the measured data. The statistical analysis was carried out by using coefficient of determination (R^2) was one of the primary criteria for selecting the best model to describe thin-layer drying curves of fish flakes. Also, there are some statistical parameters were done such as

modeling efficiency (EF), reduced chi-square ($\chi 2$) and root mean square error (RMSE) to evaluate the goodness of the fit of the selected models.

The lower the $\chi 2$ and RMSE values and the higher (R2) values and EF were chosen as the criteria for goodness of the fit. These parameters were described in the following equations (Togrul and Pehlivan 2002), (Demir, *et al.*, 2004).

$$\chi 2 = \sum_{i=1}^{N} \frac{(MRexp,i - MRpre,i)2}{N-n} \quad (3.6)$$

$$EF = \frac{(\sum_{i=1}^{N}(MRexp,i - MRexp,mean)1^2) - (\sum_{i=1}^{N}(MRpre,i - MRexp,i)^2)}{(\sum_{i=1}^{N}(MRexp,i - MRexp,mean)^2)} \quad (3.7)$$

$$RMSE = (\frac{1}{N}\sum_{i=1}^{N}(MRpre,i - MRexp,i)^2)^{\frac{1}{2}} \quad (3.8)$$

Where:

$MR_{exp,i}$ = experimental moisture ratio at observation i, dimensionless

$MR_{pre,i}$ = predicted moisture ratio at this observation i, dimensionless

$MR_{exp,mean}$ = the mean experimental moisture ratio

N = number of observations

n = number of constants in the drying model .

Table 3.1: Expressions Defining Drying Rates Given By Authors

Model Name	Expression	References
Lewis	$MR = \exp(-k \cdot t)$	Bruce (1985).
Page	$MR = \exp(-k \cdot t^{n})$	Page (1949)
Henderson and Pabis	$MR = a \cdot \exp(-k \cdot t)$	Henderson & Pabis(1961)
Logarithmic	$MR = a \cdot \exp(-k \cdot t) + c$	Togrul & Pehlivan (2002) .
Wang and Singh	$MR = 1 + a \cdot t + b \cdot t^{2}$	Wang & Singh (1978) .

The effect of initial and final moisture content, drying air temperature and relative humidity of the air on the drying constants have been investigated in many studies (Agrawal and Singh 1977; Henderson, 1974;.Ozdemir and Devres 1999; Pangavhane, et al., 1999; Yaldiz and Ertekin 2001; Yaldiz et al., 2001). The constant and coefficients of the best fitting model involving the drying variables such as temperatures and relative humidity of the drying air were determined. The effects of these variable on the constant and coefficients of drying expression were also investigated by linear regression analysis.

3.3 Optimization Experiment

.An optimization experiment was carried out after the drying experiment to determine the best conditions (Drying Temperature, Drying Time, Brine Concentration, Acid Concentration) under which the fish should be prepared to give the most favourable sensory results and shelf life. That way, the product would last longer and taste better.

Due to the number of independent variables considered in this optimization experiment, Response Surface Methodology (RSM) was used to generate a set of values to work with to avoid ambiguity. Using Minitab Version 19, a total of 30 runs were generated, with each run having varying preparation and drying conditions.

In this experiment, 50g mass of filleted fish was used as the basis. This was done by filleting the fish and cutting into standard sizes (same as kinetics experiment), then measuring 50g mass from it. Unlike in drying kinetics, sample preparation for this experiment included soaking in Brine and Acid solution. Therefore, after weighing out the

fish, the sample was soaked in brine of appropriate concentration (3 -7%) and acid solution of appropriate concentration (2 -5%) for ten minutes each. In this experiment, Propionic acd, was used to prepare the acid solution. The sample was placed in a sieve to drain for about ten minutes and reweighed to ensure it was still at 50g. The sample was then transferred into the preheated oven and dried for the specified time. After drying, the sample was left to cool. After cooling, the mass of the sample was measured and it was transferred into a clear bag. This was to allow for easy monitoring of the sample over time.

After a week, the prepared samples were assessed for spoilage and sensory evaluation was performed on them. Ten different judges were picked for this assessment to ensure the validity of the tests. This assessment was done weekly until spoilage was observed and all observations were recorded. Numerical and graphical optimization methods of optimization were carried out for the independent variables to obtain the fish moisture content with minimum percentage moisture using Minitab. A conventional graphical method was applied to obtain a minimum moisture level. Predictive models were used to represent the systems graphically. Response surface plots of the response variables were utilized to select optimum combinations of drying temperature, thickness, salt concentration, and drying time for the drying of Blue Whiting fish.

Table 3.2 Summary of Runs Generated with Minitab

Run Order	Drying Time(min)	Drying Temp (^{0}C)	Brine solution (%)	Acid solution (%)
1	180	70	6	4
2	150	70	4	4
3	150	70	6	2
4	180	80	6	2
5	150	80	4	2
6	165	75	5	3
7	150	80	6	4
8	180	70	4	2
9	165	75	5	3
10	180	80	4	4
11	165	75	3	3
12	165	75	5	3
13	165	75	7	3
14	165	75	5	5
15	165	75	5	1
16	135	75	5	3
17	165	75	5	3
18	165	65	5	3
19	195	75	5	3
20	165	85	5	3
21	180	80	6	4
22	165	75	5	3
23	180	70	6	2
24	180	70	4	4
25	150	80	6	2
26	150	80	4	4
27	165	75	5	3
28	180	80	4	2
29	150	70	6	4
30	150	70	4	2

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effect of Drying Temperature and Time on the Moisture Ratio

Figure 4.1 shows the drying curves of Blue Whiting fillet at different temperatures (60, 70, 80,90 and 100^{o}C). It is observed that the Moisture Ratio of the blue whiting fillets decreased with increased drying time.

The sharp decrease in moisture content at the start of drying (as seen in Figure 4.1) indicates a rapid moisture removal from the sample surface. This was due to the availability of free moisture which was removed. Reduced moisture removal towards the end of the experiment could be due to a decrease in moisture content. This is due to the fact that blue whiting fillets contain a considerable amount of bulk water which was removed initially at a much faster rate.

The graph of drying rate versus drying time for a blue whiting sample at different temperatures is shown in Figure 4.2. It was observed that at the start of drying, the pace of drying increased rapidly then began to slow, possibly due to the delayed internal to outward moisture transfer, implying that blue whiting may not be as porous as other fish for easy moisture transport. The drying rate, being temperature dependent, increased as the drying temperature increased.

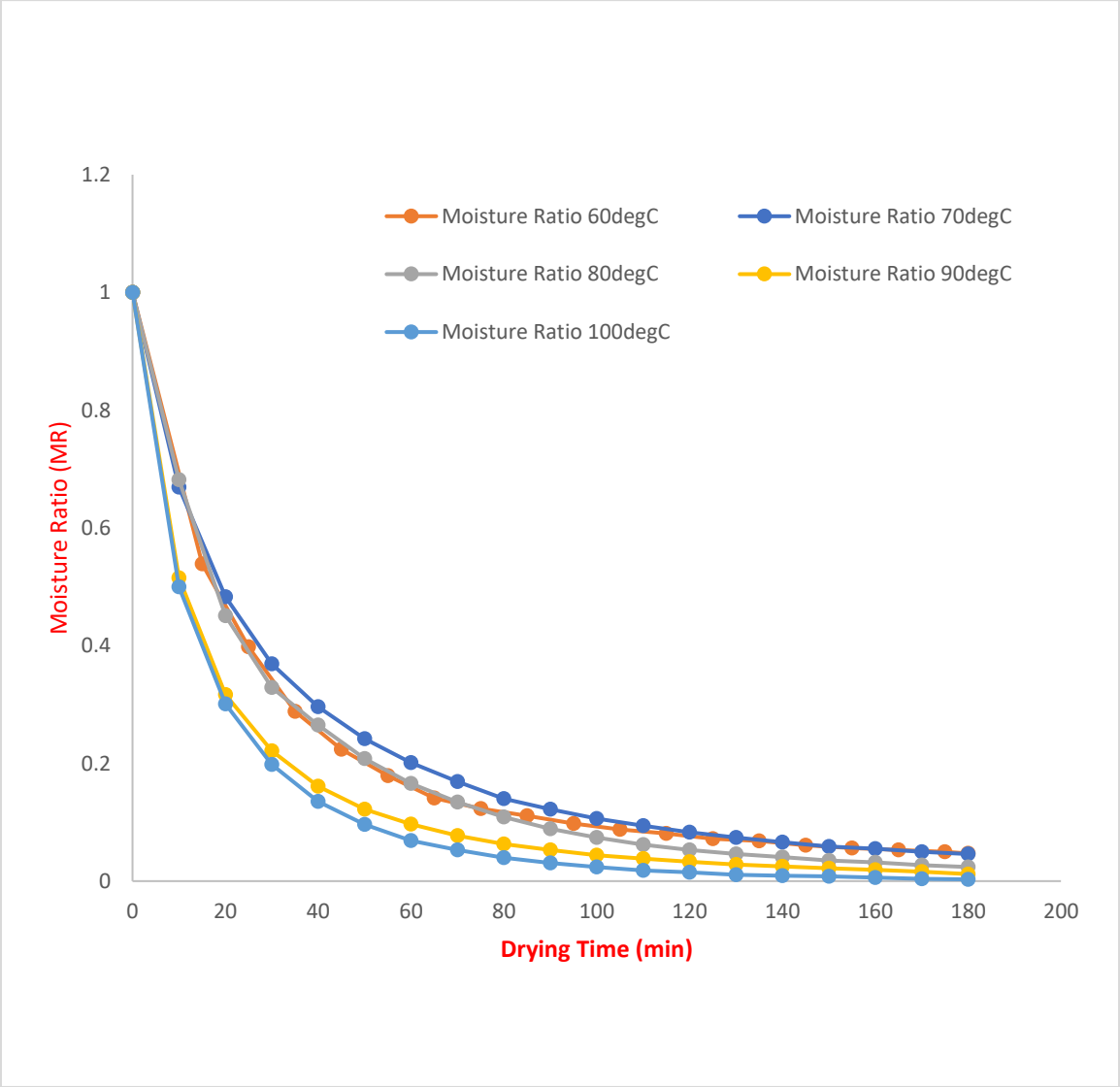


Figure 4.1 Graph of Moisture Ratio versus Drying Time for the drying of blue whiting fillets.

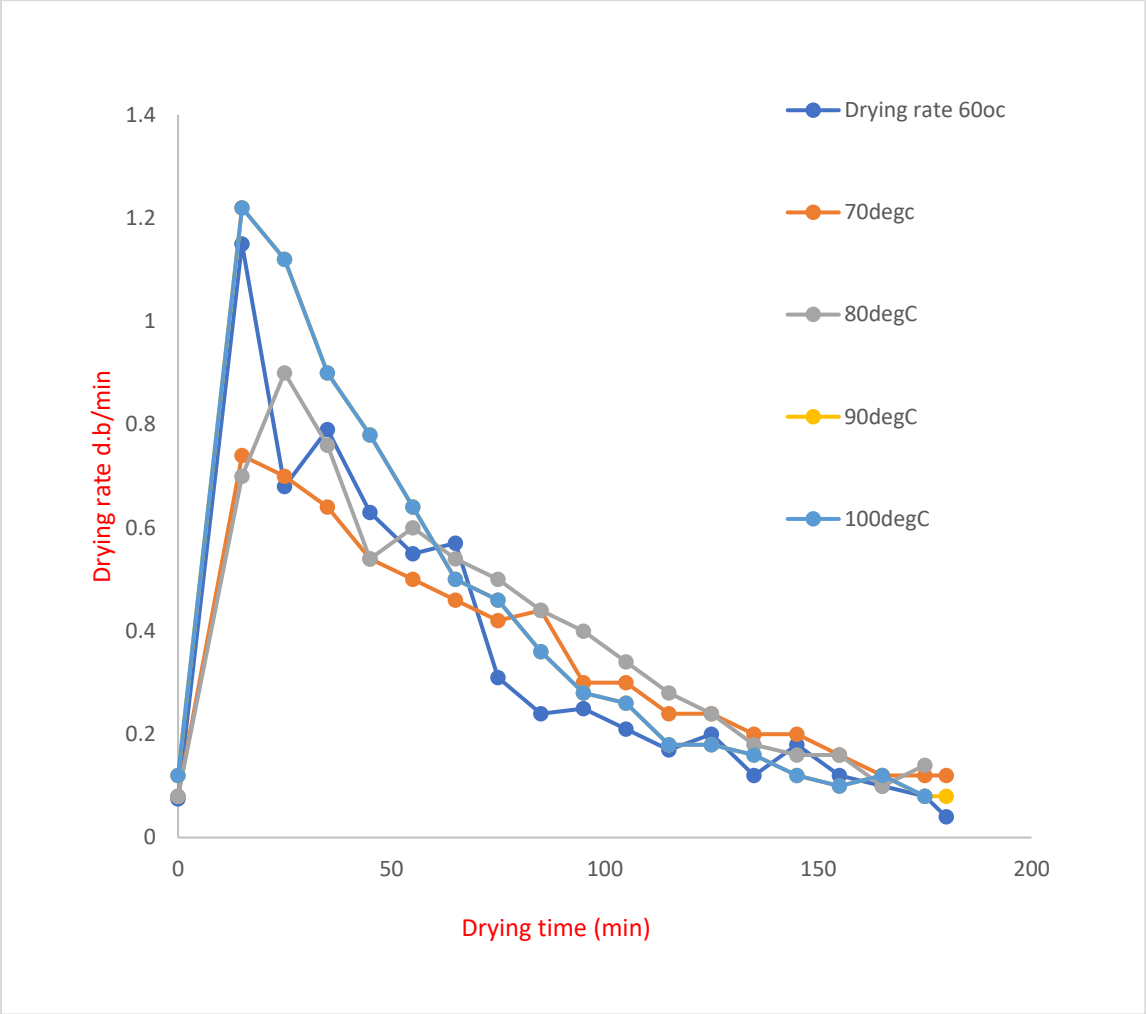


Figure 4.2 Graph of Drying Rate versus Drying Time for the drying of blue whiting fillets.

4.2 Modelling of the Drying Kinetics and Fitting of the Drying Curves.

The moisture content data observed in the drying experiment under different conditions were fitted to 3 thin-layer drying models listed in Table 3.1. This was done to characterize the drying kinetics of Blue Whiting fish. The statistical results of different models such as coefficient of determination (R^2), the reduced chi-square ($\chi 2$) and the root mean square error (RMSE) values are summarized in Table 4.1.

The logarithmic model was shown to be the best model for moisture ratio prediction at 60^0C, while the Page model was found to be the most suited for the description of experimental kinetic data at all following temperatures with the lowest X^2 and RMSE values, respectively. These results are illustrated in Figure 4.3 to 4.17.

Table 4.1 Comparison of different models with parameters for drying of blue whiting

Model Name	Temperature (^{O}C)	Constants	R^2	X^2	RMSE
Page	60	k= 0.1113 n= 0.6667	0.7194	0.0019992	0.0424186
Henderson and Pabis	60	a = 0.9417 k = 0.0303	0.8175	0.0002755	0.0157467
Logarithmic	60	b = 0.9214 k = 0.0402 c = 0.0649	0.7448	0.00018095	0.01240222
Page	70	k= 0.088 n = 0.7038	0.8329	0.000108	0.00986
Henderson and Pabis	70	a = 0.9177 k = 0.0259	0.823	0.00181748	0.0404442
Logarithmic	70	b = 0.9006 k = 0.0349 c = 0.0670	0.7996	0.0004095	0.01865745
Page	80	k= 0.0739 n = 0.7778	0.8155	0.00017181	0.01243502
Henderson and Pabis	80	a =0.9528 k = 0.0312	0.8052	0.00100174	0.03002616

Logarithmic	80	b = 0.9384 k = 0.0372 c = 0.0424	0.7852	0.00031802	0.01644132
Page	90	k= 0.1518 n = 0.6657	0.8263	0.00006806	0.00782682
Henderson and Pabis	90	a = 0.9536 k = 0.0488	0.7187	0.00137393	0.035164551
Logarithmic	90	b = 0.0715 k = 0.0415 c = 0.0261	0.7584	0.00397561	0.058131534
Page	100	k= 0.1286 n = 0.7407	0.7014	0.00001137	0.00319886
Henderson and Pabis	100	a = 0.9690 k = 0.0550	0.6887	0.00064656	0.02412279
Logarithmic	100	b = 0.9581 k = 0.0598 c = 0.206	0.6682	0.00040017	0.01844308

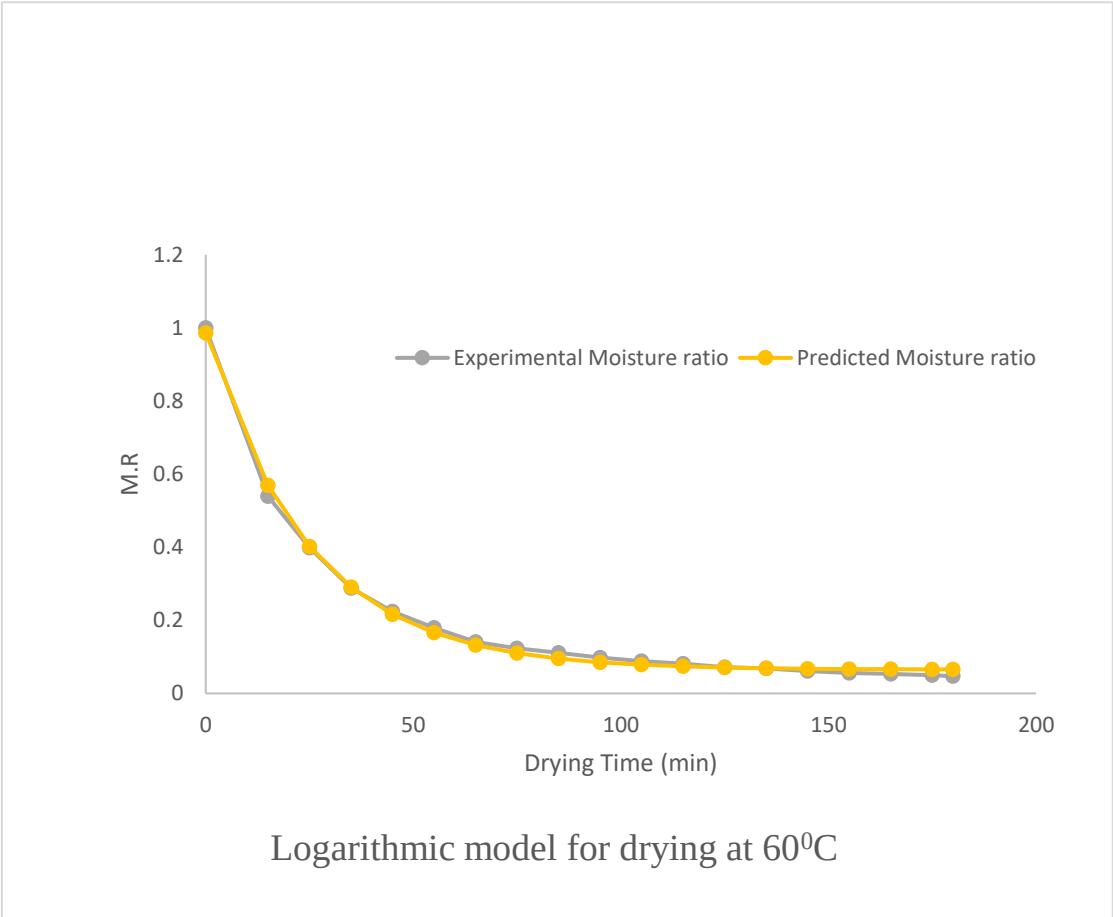


Figure 4.3 Prediction of experimental moisture ratio as a function of drying time at 60^0C using logarithmic drying model

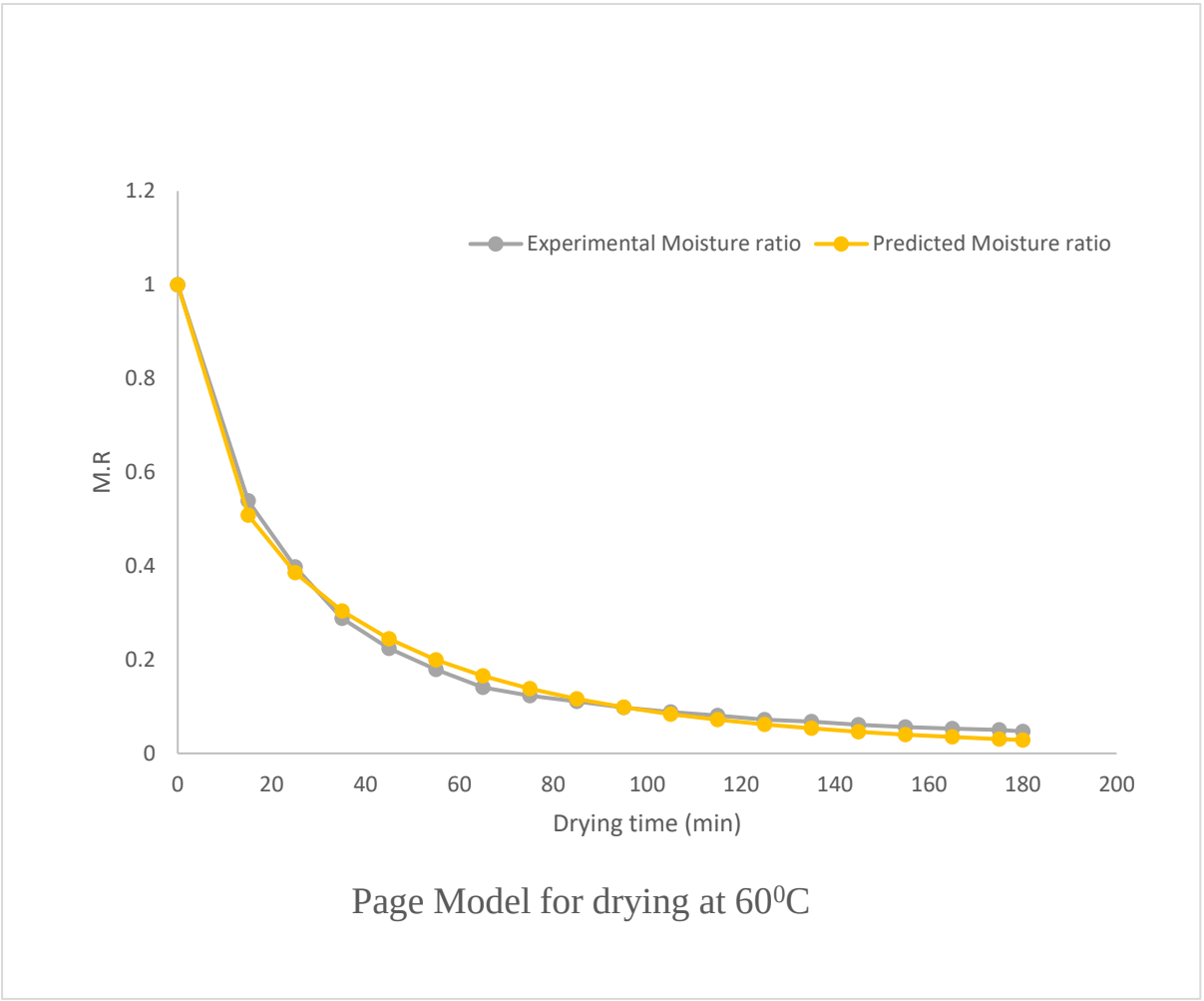


Figure 4.4 Prediction of experimental moisture ratio as a function of drying time at 60^{0}C using Page model.

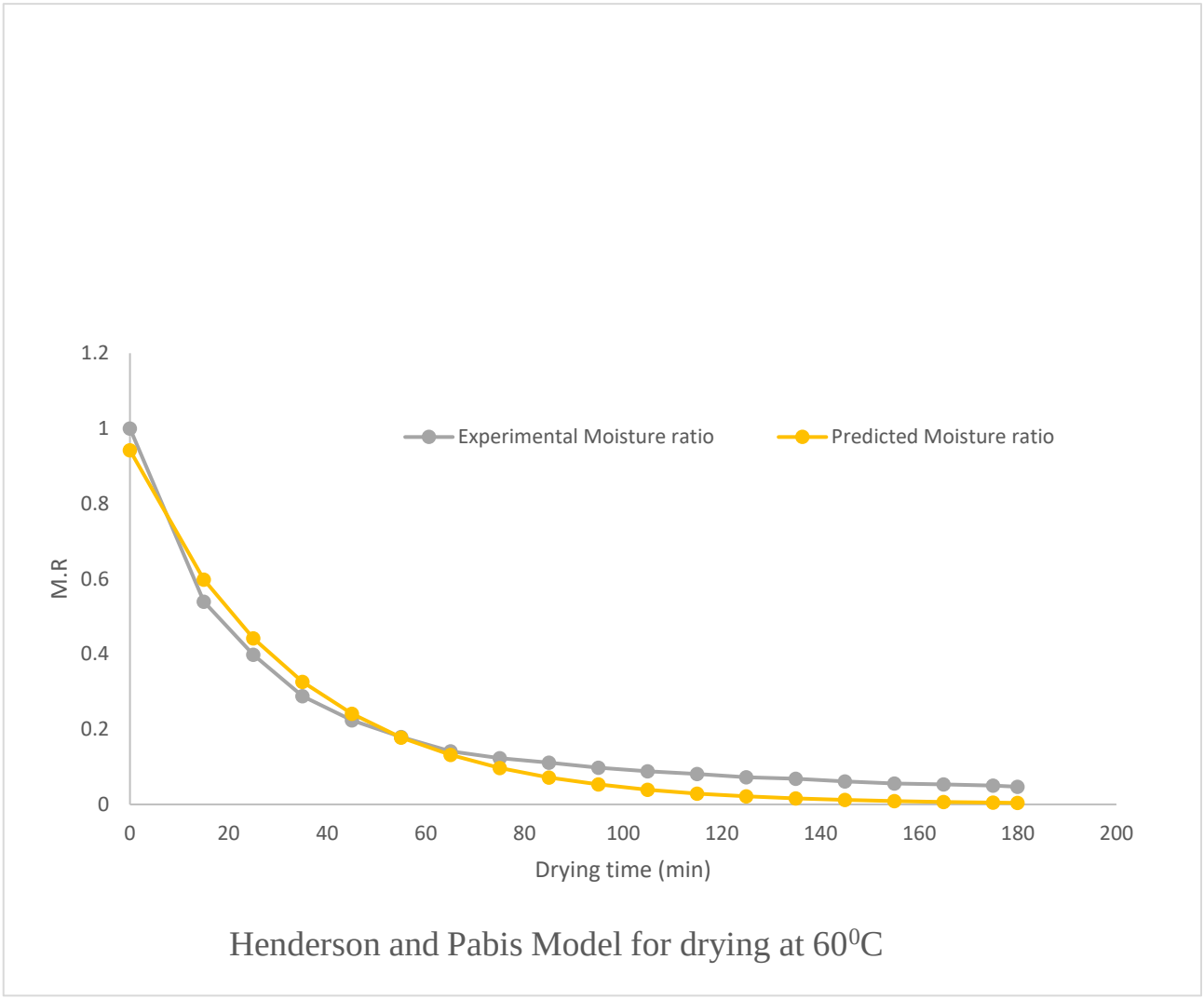
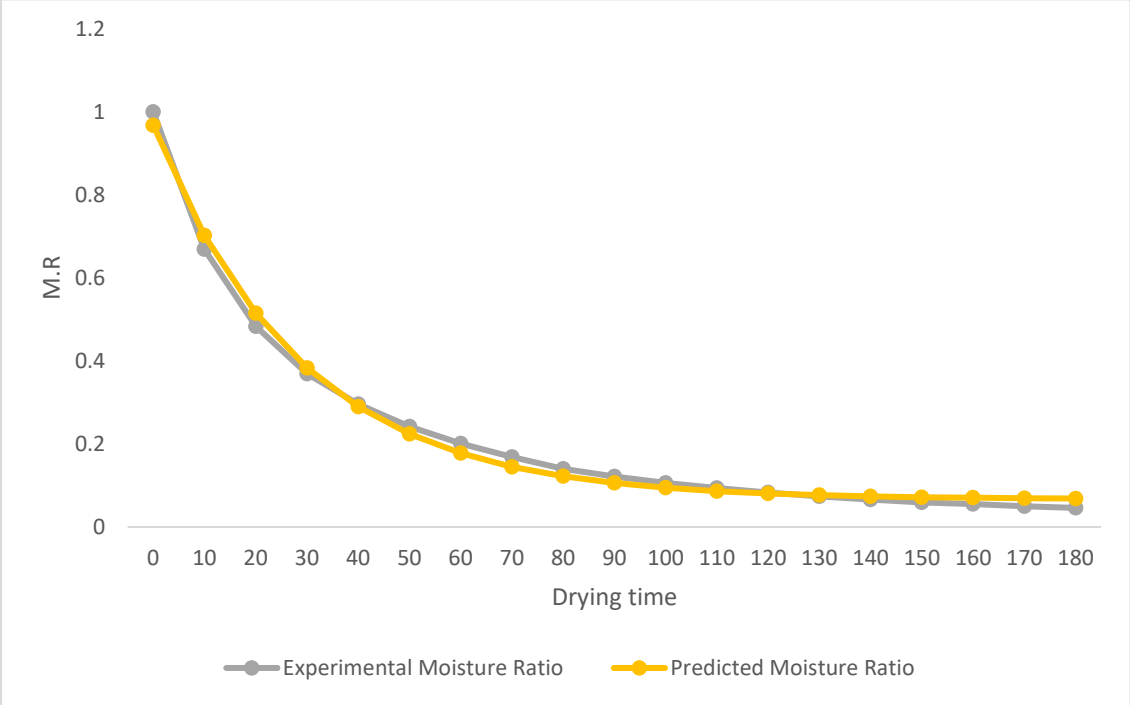
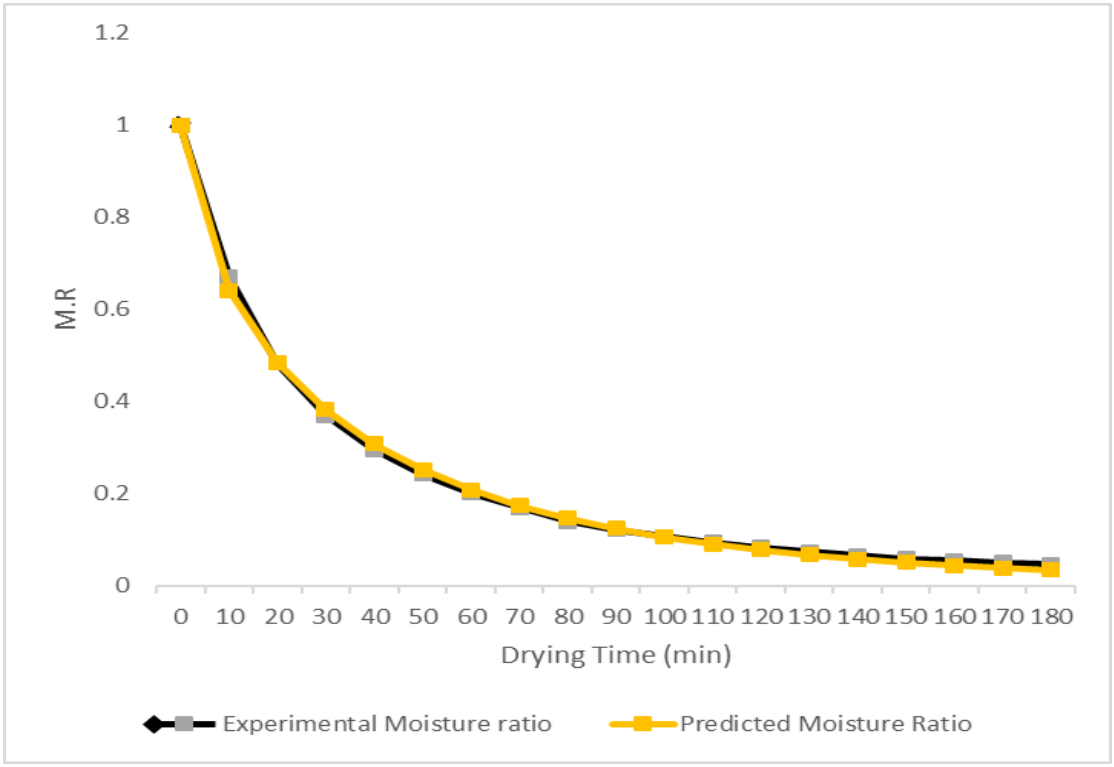


Figure 4.5 Prediction of experimental moisture ratio as a function of drying time at 60^{0}C using Henderson and Pabis model



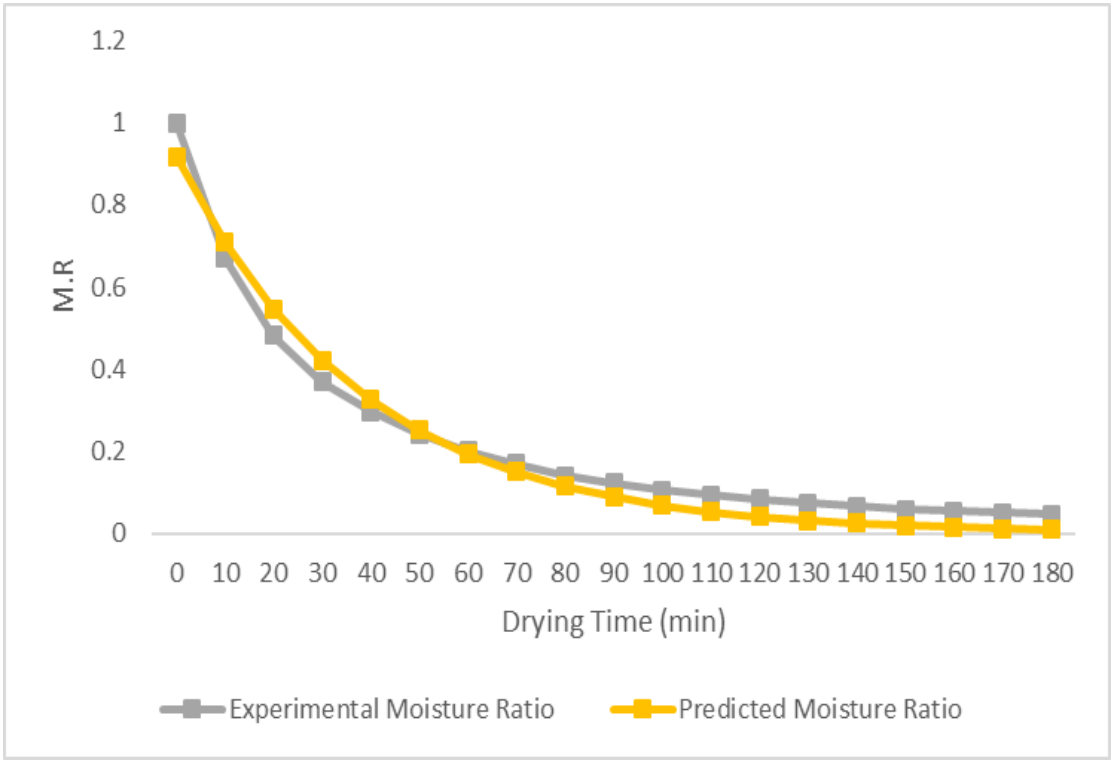
Logarithmic model for drying at 70^0C

Figure 4.6 Prediction of experimental moisture ratio as a function of drying time at 70^0C using Logarithmic model



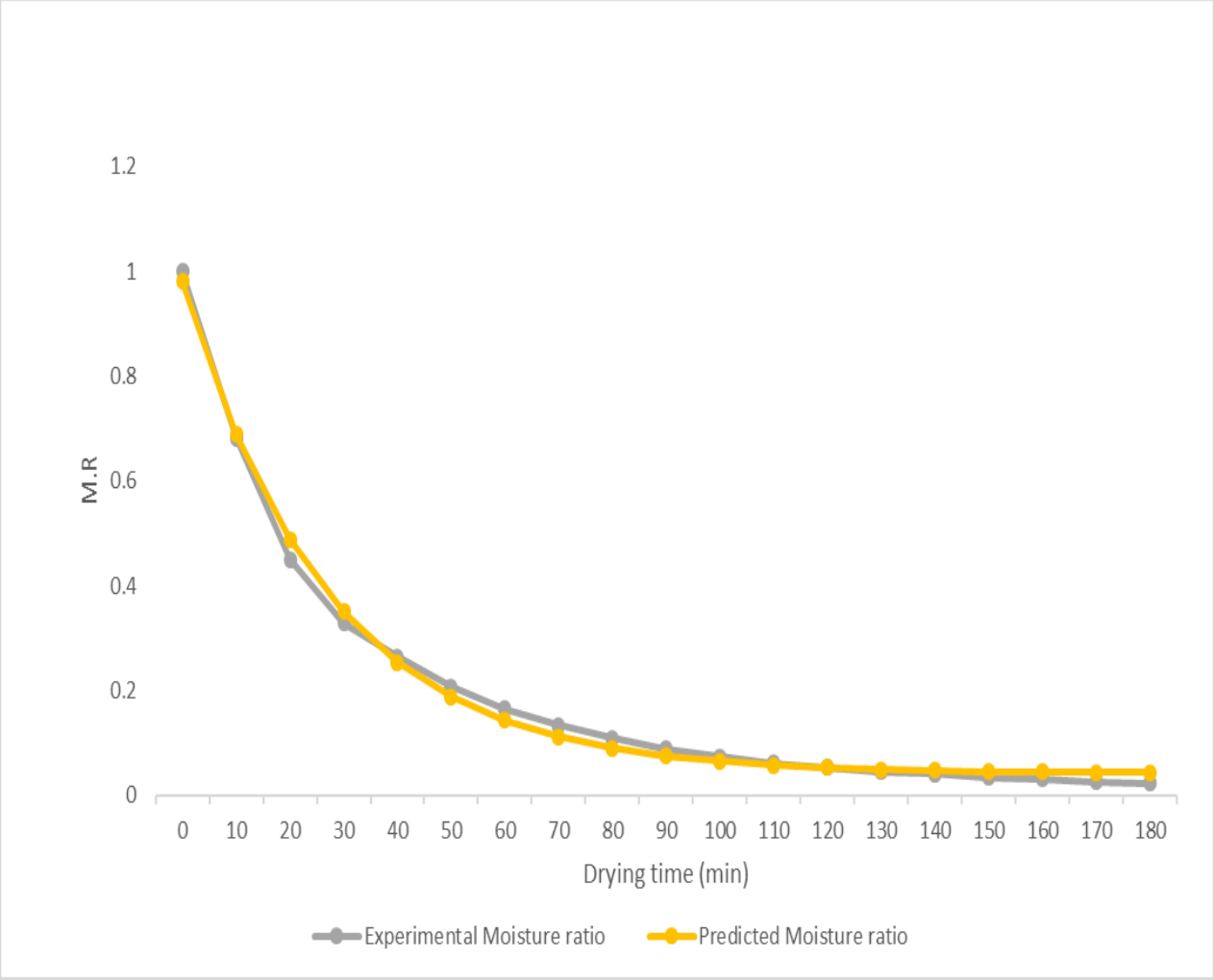
Page Model for drying at 70^0C

Figure 4.7 Prediction of experimental moisture ratio as a function of drying time at 70^0C using Page model



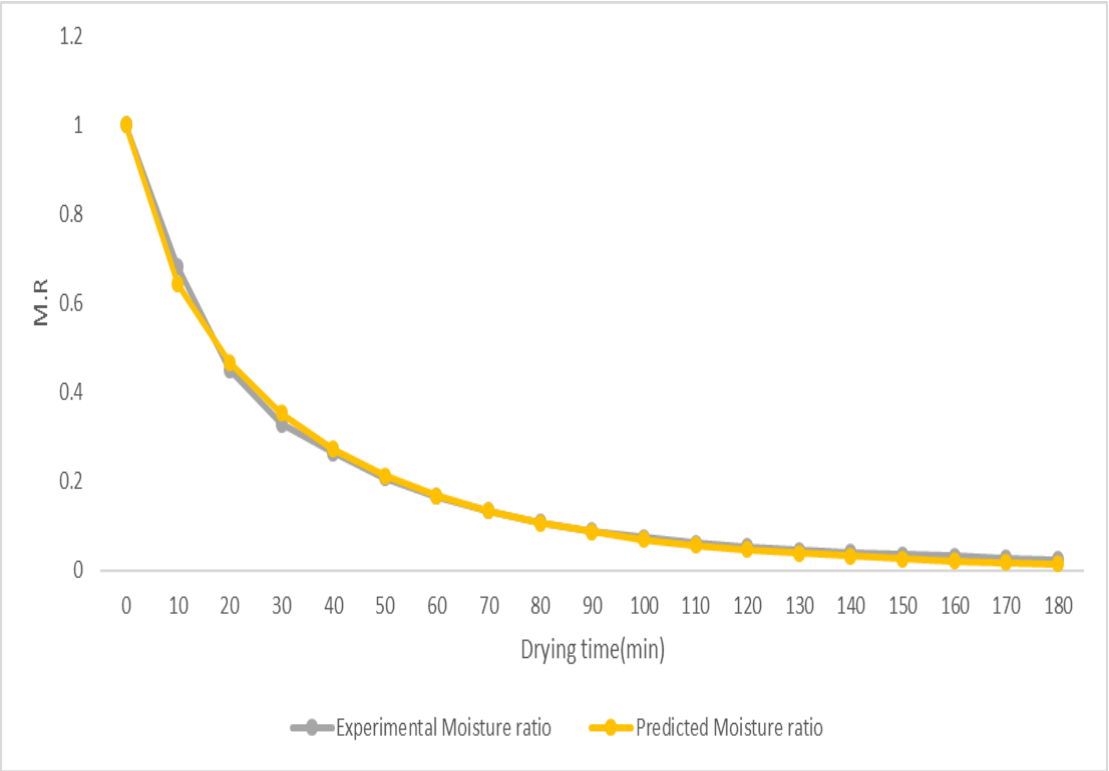
Henderson and Pabis Model for drying at 70 ^{0}C

Figure 4.8 Prediction of experimental moisture ratio as a function of drying time at 70 ^{0}C using Henderson and Pabis Model



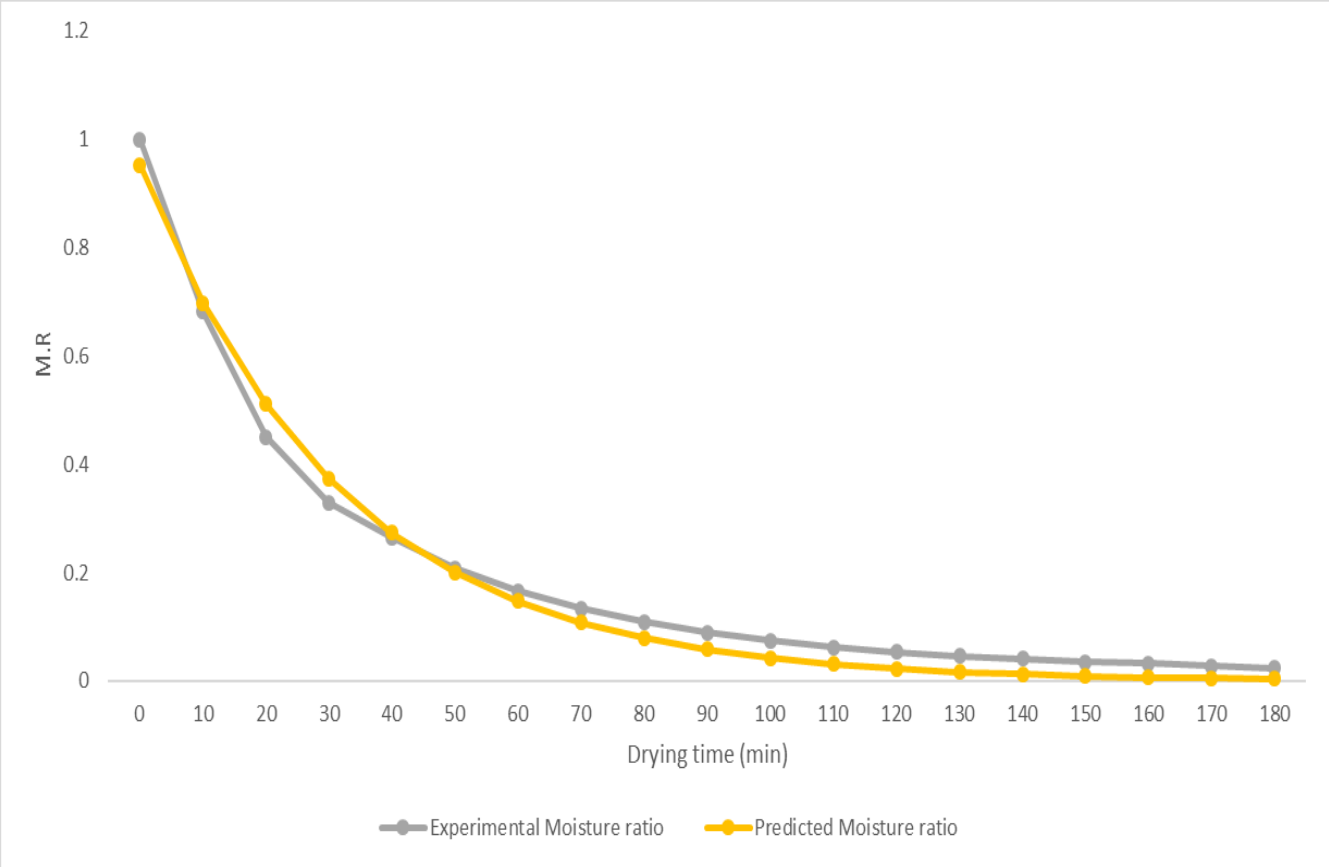
Logarithmic model for drying at 80 ^{0}C

Figure 4.9 Prediction of experimental moisture ratio as a function of drying time at 80 ^{0}C using logarithmic model



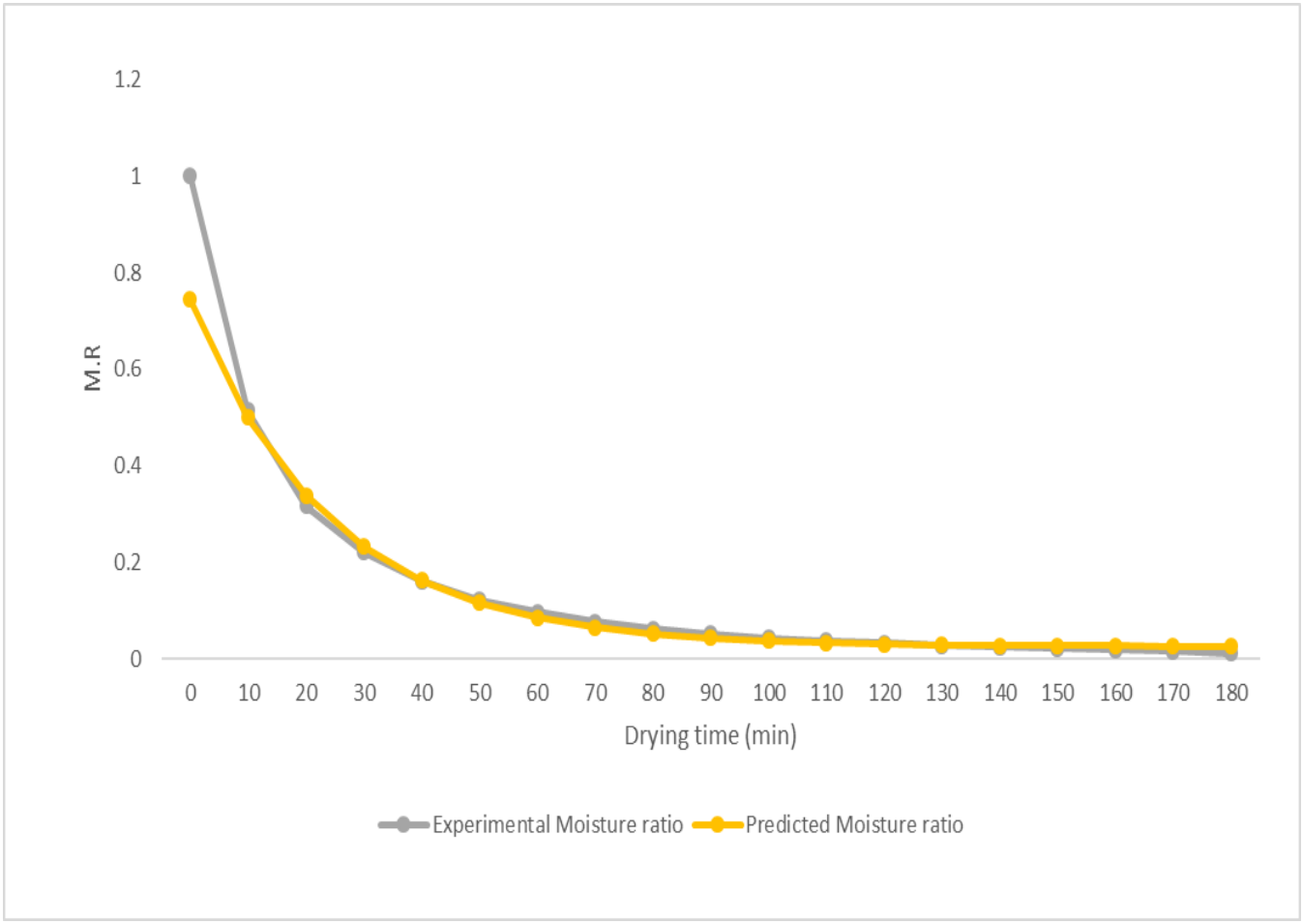
Page Model for drying at 80^0C

Figure 4.10 Prediction of experimental moisture ratio as a function of drying time at 80^0C using Page model



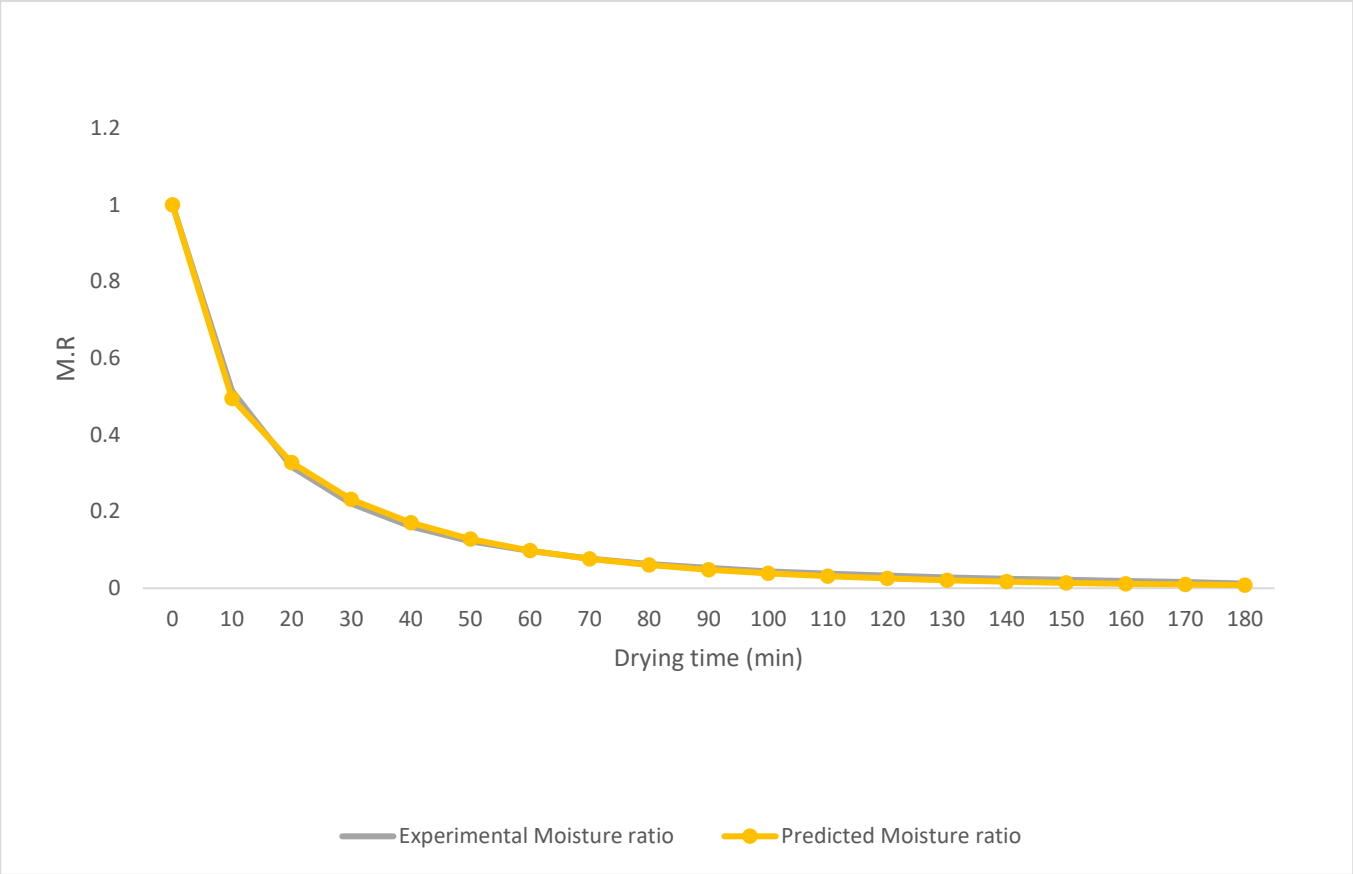
Henderson and Pabis Model for drying at 80°C

Figure 4.11 Prediction of experimental moisture ratio as a function of drying time at 80^0C using Henderson and Pabis model



Logarithmic model for drying at 90^0C

Figure 4.12 Prediction of experimental moisture ratio as a function of drying time at 90^0C using Logarithmic model



Page Model for drying at 90^{0}C

Figure 4.13 Prediction of experimental moisture ratio as a function of drying time at 90^{0}C using Page model

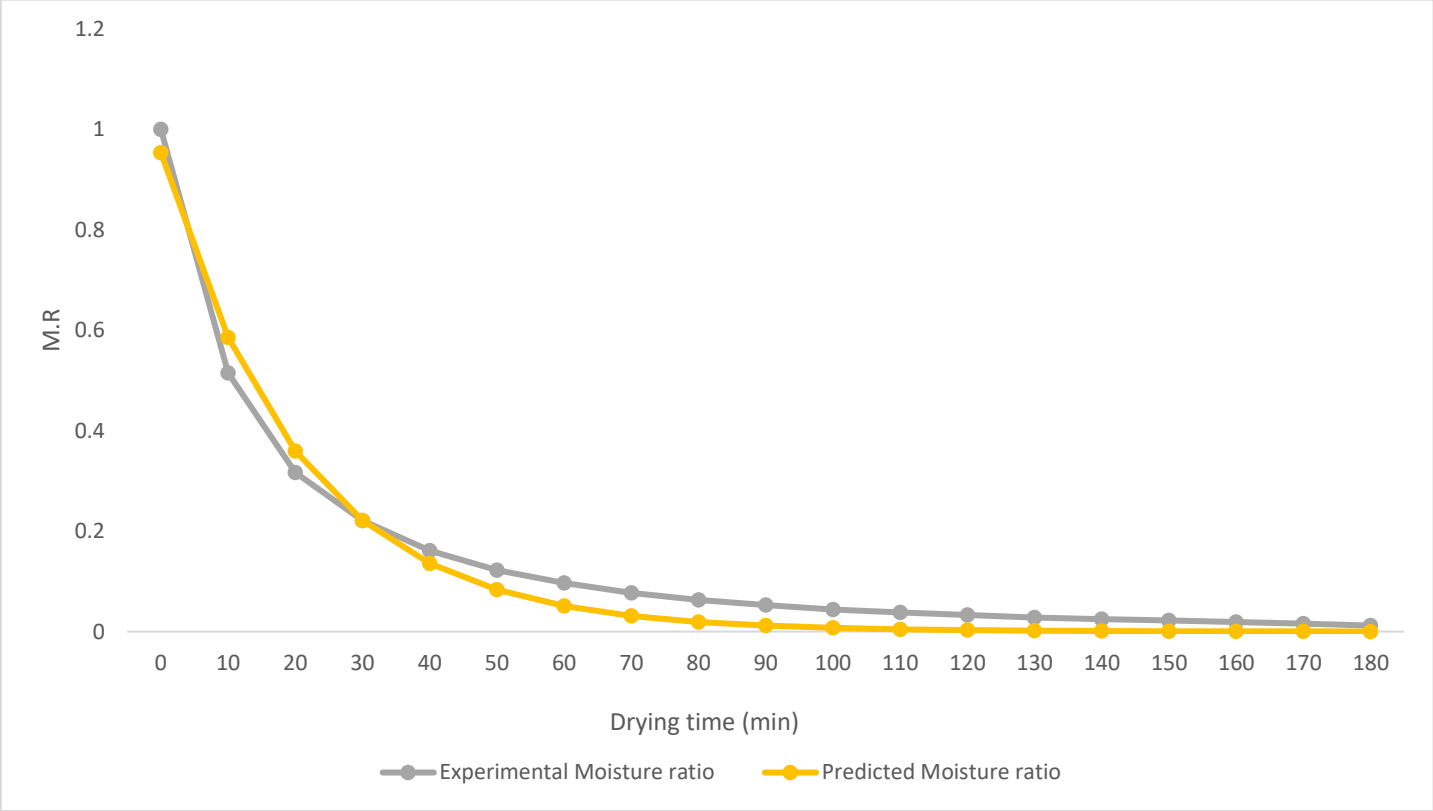
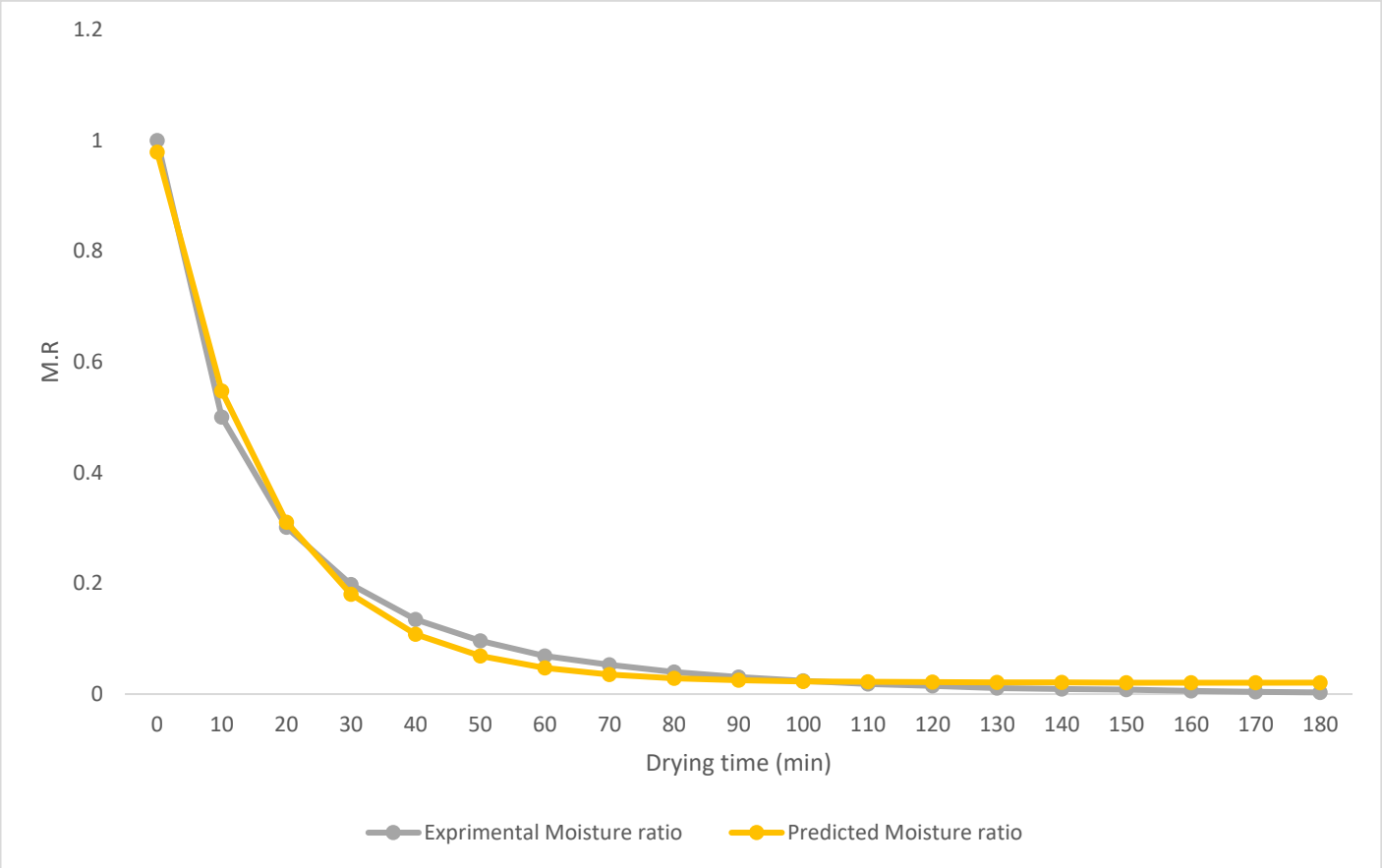
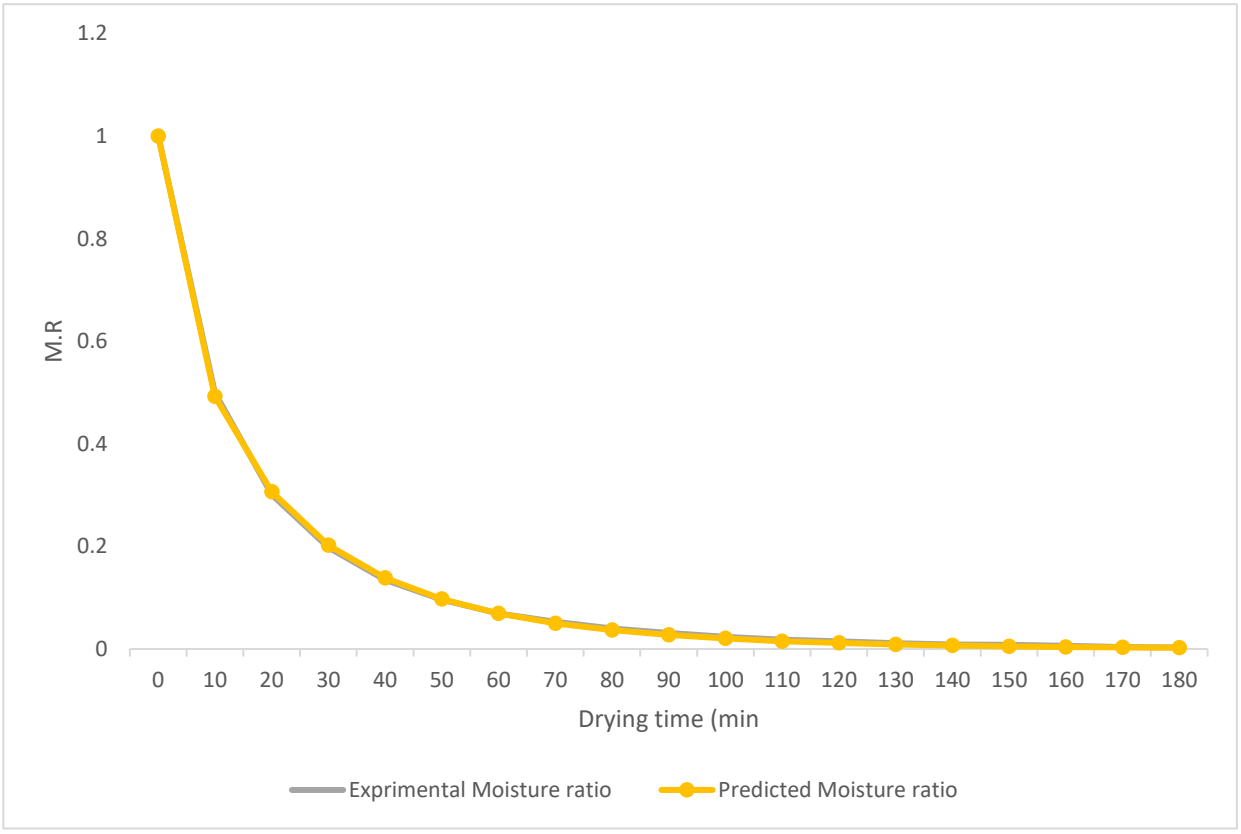


Figure 4.14 Prediction of experimental moisture ratio as a function of drying time at 90^{0}C using Henderson and Pabis model



Logarithmic model for drying at 100 ^{0}C

Figure 4.15 Prediction of experimental moisture ratio as a function of drying time at 100^{0}C using Logarithmic model



Page Model for drying at 100^0c

Figure 4.16 Prediction of experimental moisture ratio as a function of drying time at 100^0c using Page model

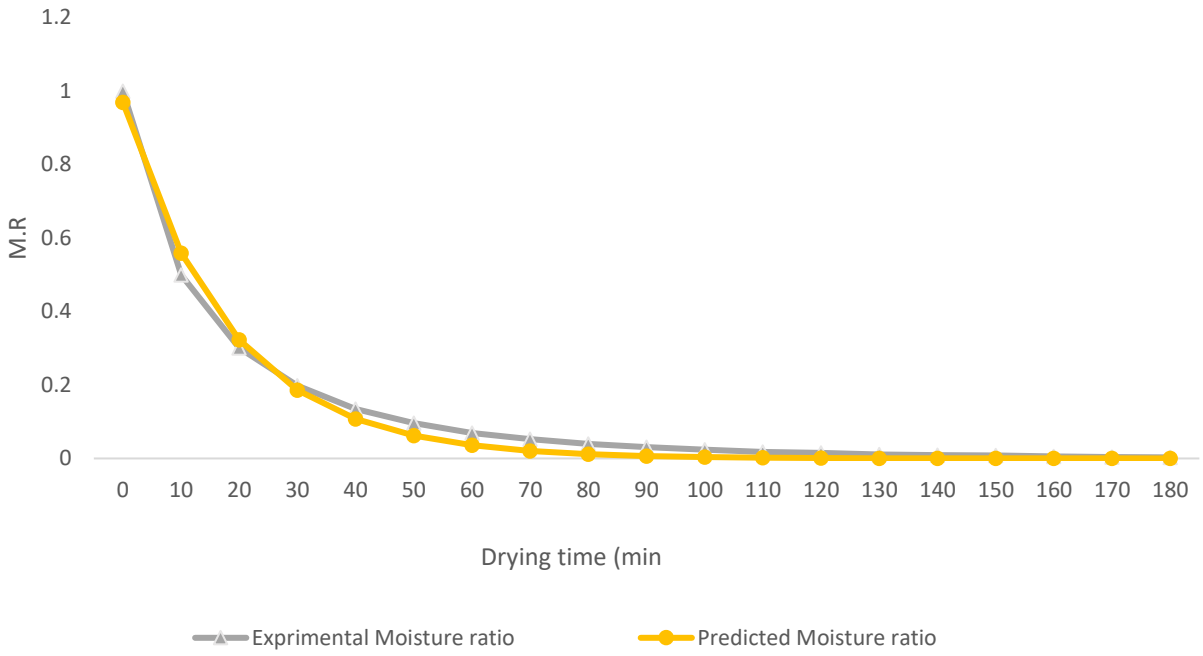


Figure 4.17 Prediction of experimental moisture ratio as a function of drying time at 100^{0}c using Henderson and Pabis model

4.3 Effect Of Temperature On The Coefficient Of Moisture Diffusion

The diffusivity was estimated using linear regression using the ln (MR) slope against time relationship, as shown in Figure 4.18. The results have shown that internal mass transfer resistance controls the drying time due to the presence of a falling rate drying periode. As a result, the effective moisture diffusivities at the drying experiment under various conditions are computed and displayed in Table 4.2 using Eqn. (3.3) from Fick's second law.

The effective moisture diffusivities of blue whiting fillets with thickness of 5 mm at drying temperature 60, 70 , 80, 90 and 100°C are in the range of [3.6565 x 10^{-11} to 6.994 x 10^{-11} m^2 /s], which were consistent with the previous studies that the values of the effective moisture diffusivities ranged from 10^{-9} to 10^{-11} m^2 /s (Madamba, 1996), from 10^{-8} to 10^{-12} m^2 /s (Zogzas, *et al.*, 1996) for food materials. The values of D_{eff} are comparable with the reported values of 3.32 – 90.0 × 10^{-10} m^2 /s for berberis fruits at 50–70°C (Aghbashlo, *et al.*, 2008), and 6.27 – 35.0 × 10^{-10} m^2 /s for orange slices at 40–80°C (Rafiee et al., 2010). The values of the effective moisture diffusivities increase with increasing drying temperature in the same thickness of blue whiting fillets, mirroring the increase in moisture diffusivity. This phenomenon can be explained by the fact that the increased heat of raising the drying temperature causes a major increase in the movement of water molecules, resulting in an increase in the water diffusion rate.

Table 4.2 The effective moisture diffusivities of blue whiting fillets at different conditions

Temperature T/^{o}C	Drying time (seconds)	Linear simulated equation(most appropriate trendline)	R^2	Slope M	$D_{eff}/m^2/s$
60	10800	lnMR = -0.1559t - 0.3382	0.9063	-0.1559	3.6565×10^{-11}
70	10800	lnMR = -0.1643t - 0.0972	0.9606	-0.1643	3.8535×10^{-11}
80	10800	lnMR = -0.2004t - 0.0139	0.9741	-0.2004	4.7001×10^{-11}
90	10800	lnMR = -0.2210t - 0.2426	0.9515	-0.2210	5.1833×10^{-11}
100	10800	lnMR = -0.2982t + 0.0012	0.9823	-0.9823	6.994×10^{-11}

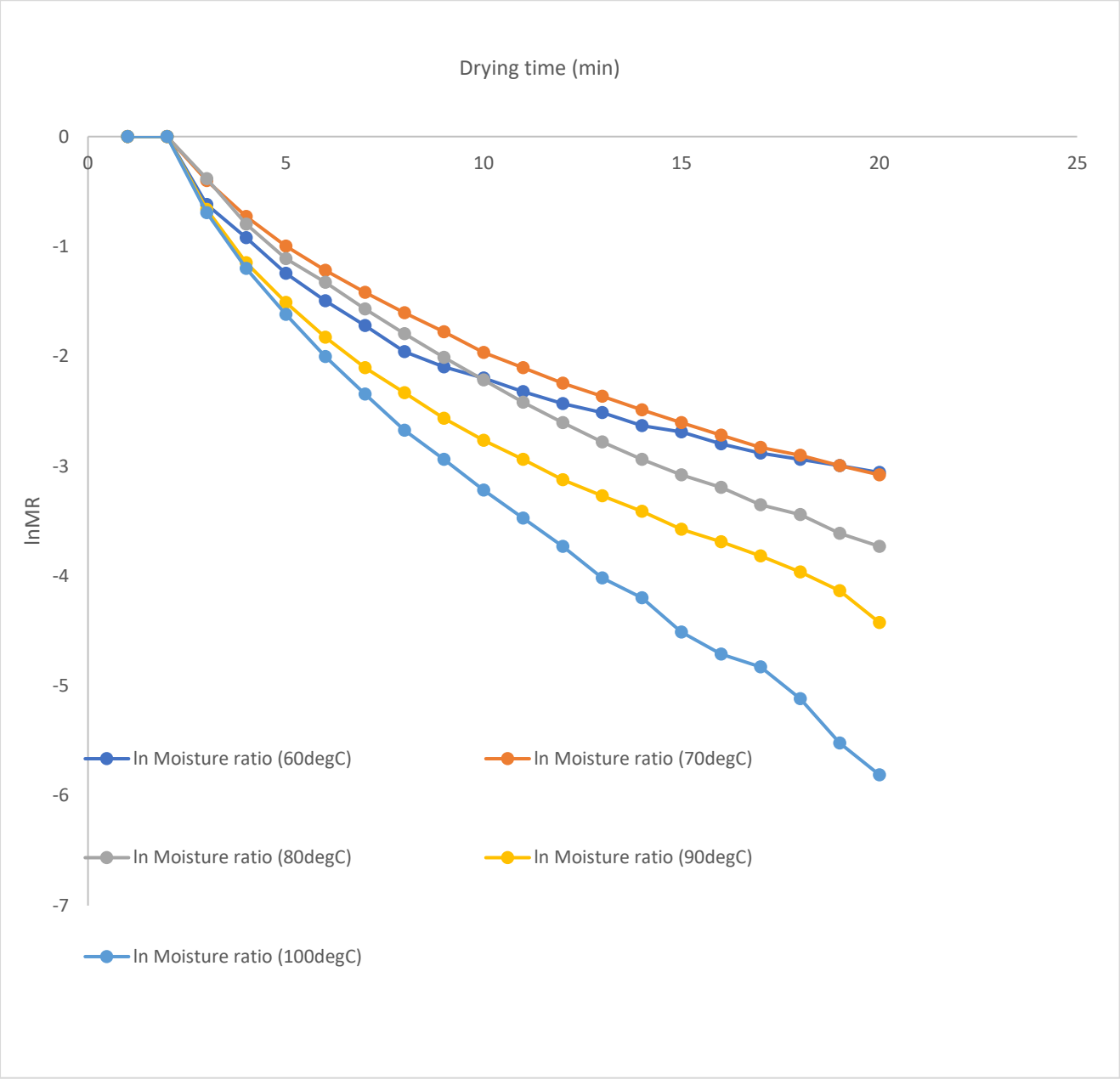


Figure 4.18 Plot of ln (MR) against Time

4.4 Optimization Experiment Results

The moisture content was quantitatively investigated during the drying process using Response Surface Methodology (RSM). The effects of variation in the moisture level of the Blue Whiting fish were studied by changing the drying temperature, the thickness of the product, salt concentration, and duration of drying, and a second-order polynomial equation was fitted with the experimental data. A two-factorial interaction (2FI) regression model describing the effects of these variables on the moisture content was then developed. Table 4.3 highlights the variation in the sample moisture content as the process conditions were altered.

4.5 Statistical Analysis of result on model fitting

The experimental response (moisture content) as a function of drying process conditions like Drying Time (A), Drying Temperature (B)**,** Salt Concentration (C)**,** and Acid Concentration (D) during drying of Blue Whiting fillets are presented in Table 4.8. The moisture content value (% wet basis) was within the range of 0.80–36.20%. Regression analysis and ANOVA results of the 2 Factor Integration model are shown in Tables 4.4 and 4.5. The model F-values of the response was 5.06, implying that the model is significant. At the same time, the moisture content showed an insignificant p-value of lack-of-fit, meaning that the model for predicting the moisture level of dried blue whiting fish was fitted and reliable. The adequacy of the model was further checked by the Coefficient of determination (R^2) and was found to be 0.6947 (Table 4.9). A high value of the coefficient of determination obtained for the response variable indicated that the developed model for MC accounted for and adequately explained 69.47% of the total variation.

4.6 Effect of drying process variables on moisture content

The moisture level is an important parameter in seafood processing. It indicates the amount of water evaporated from the sample when subjected to any form of heat. The regression equation which describes the effects of drying process variables on moisture content in terms of actual values of the variable, is given in the equation below

$$\mathbf{MC} = -775 + 1.70\,A + 14.20\,B + 62.5\,C + 18.24\,D - 0.00556\,A^{*}A - 0.0882\,B^{*}B - 3.08\,C^{*}C - 3.01\,D^{*}D - 0.430\,B^{*}C$$

Where: MC – Moisture Content (%); A – Drying Time (min); B – Drying Temperature (◦); C – Salt Concentration (%); D – Acid Concentration (%)

The positive linear terms indicate that moisture level in the fish increased with increase in Drying Time, Drying Temperature, Salt Concentration and Acid Concentration. The presence of negative interaction terms between Drying Temperature and Salt Concentration indicated that increase in their levels decreased the moisture content of the product. While, the negative squared interaction terms (AA, BB, CC, DD), indicated that increase in their levels further decreased moisture content of the product during the drying process. To visualize the combined effects of four variables on the moisture content of the product during the drying process, the response surface plots

Table 4.3

Results for moisture content in the processed Blue Whiting fish observed under varying process conditions.

Run Order	Drying Time(min)	Drying Temp (^{0}C)	Brine solution (%)	Acid solution (%)	Moisture Content (%)
1	180	70	6	4	18.40
2	150	70	4	4	16.60
3	150	70	6	2	21.60
4	180	80	6	2	2.80
5	150	80	4	2	13.60
6	165	75	5	3	21.40
7	150	80	6	4	13.00
8	180	70	4	2	12.00
9	165	75	5	3	20.20
10	180	80	4	4	10.40
11	165	75	3	3	17.40
12	165	75	5	3	29.00
13	165	75	7	3	12.60
14	165	75	5	5	7.20
15	165	75	5	1	23.40
16	165	75	5	3	24.20
17	165	75	5	3	28.00
18	165	65	5	3	36.20
19	195	75	5	3	21.40
20	165	85	5	3	0.80
21	180	80	6	4	6.40
22	165	75	5	3	28.40
23	180	70	6	2	9.80
24	180	70	4	4	16.20
25	150	80	6	2	2.60
26	150	80	4	4	13.80
27	165	75	5	3	18.00
28	180	80	4	2	5.80
29	150	70	6	4	28.20
30	150	70	4	2	17.60

TABLE 4.4

Regression Analysis for response surface 2-Factor Interaction model.

Regression Terms	Value
R^2	0.6947
Adjusted R^2	0.5573
Standard Deviation	5.8388

TABLE 4.5

ANOVA for response surface 2FI model for moisture content of dried fish

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
Model	9	1551.60	172.400	5.06	0.001
Linear	4	928.56	232.139	6.81	0.001
A	1	71.11	71.109	2.09	0.164
B	1	849.66	849.660	24.92	0.000
C	1	6.83	6.827	0.20	0.659
D	1	0.96	0.960	0.03	0.868
Square	4	556.64	139.159	4.08	0.014
A*A	1	25.66	25.659	0.75	0.396
B*B	1	135.16	135.157	3.96	0.060
C*C	1	263.63	263.628	7.73	0.012
D*D	1	250.95	250.950	7.36	0.013
2-Way Interaction	1	73.96	73.960	2.17	0.156
B*C	1	73.96	73.960	2.17	0.156
Error	20	681.85	34.093		
Lack-of-Fit	14	564.46	40.318	2.06	0.191
Pure Error	6	117.39	19.566		
Total	29	2233.45			

Note: A – Drying Time

B – Drying Temperature

C – Salt Concentration

D – Acid Concentration

(Fig. 4.5) were generated for the fitted model as a function of two variables, thereby keeping the third variable at its central point. Perry, in 2007 reported that drying period during which the instantaneous drying rate continually decreased which was referred to as the falling rate period and that the falling rate is significantly affected by drying temperature. The higher temperatures and time seem to accelerate the rate of moisture loss through shrinking of cell membranes as well as the better moisture transfer characteristics on the product surface (Bellagha, et al, 2002). The moisture level in the product decreased with an increase in the drying temperature and an increase in the drying time in the process. Figure 4.2 shows the degree to which each independent variable affects the resulting moisture content.

4.7 Numerical optimization of drying process conditions

The criteria for the variables were set such that the independent variables (temperature, drying time, salt concentration, and brine concentration) would be minimum looking at an economic point of view. The measure for constraints optimization was the minimum possible moisture content in the fish product. For optimizing the process parameters for the drying process by numerical optimization, which finds a point that maximizes the desirability function, equal importance of '3' was given to all the four drying process parameters and the response. The optimum conditions were found to be at Drying Time = 184.74 min; Drying Temperature = 80.24^0c; Salt Concentration = 6.04%; Acid Concentration = 2.26%. At these conditions, the moisture content was 3.115%.

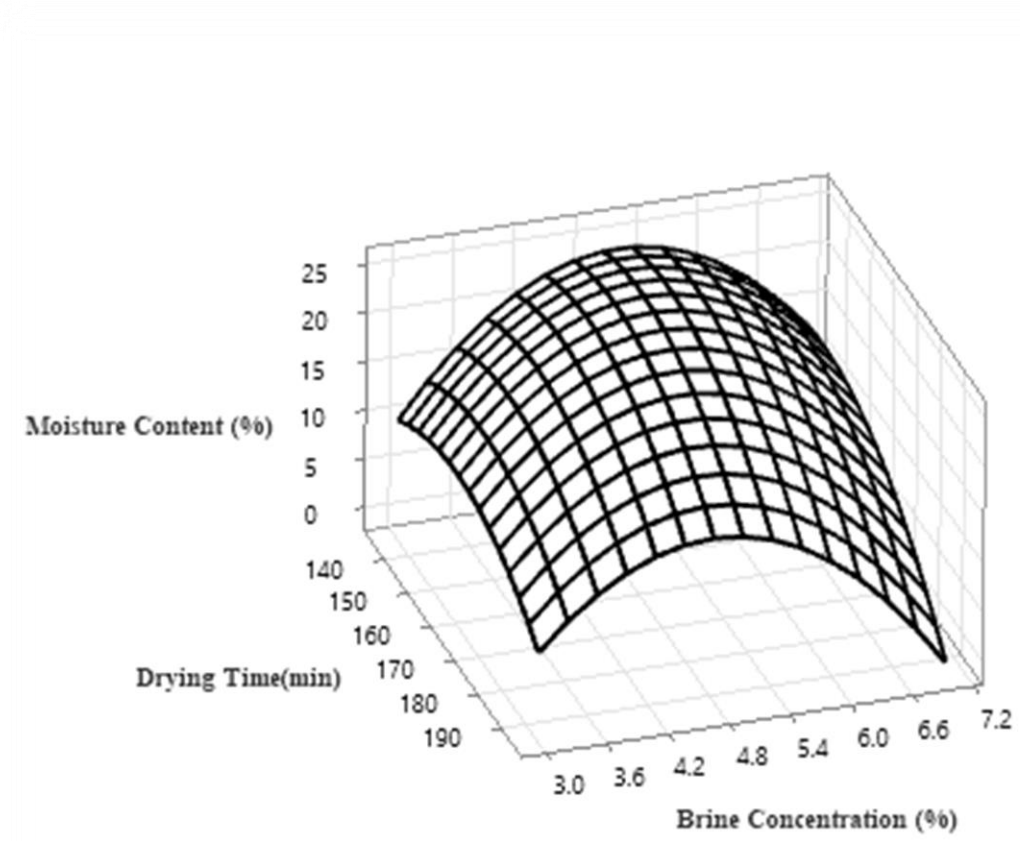


Figure 4.19: Surface Plot of Moisture Content (%) vs Brine Concentration (%), Drying Time (min)

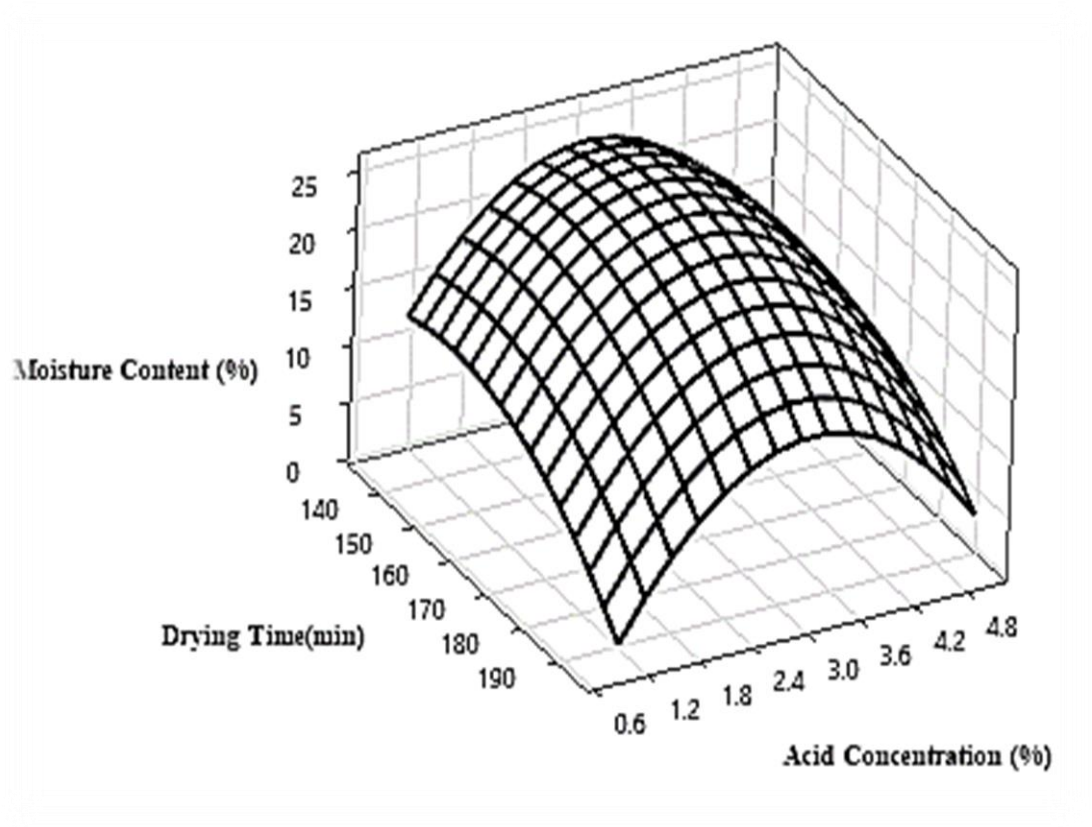


Figure 4.20: Surface Plot Of Moisture Content (%) vs Acid Concentration (%), Drying Time (min)

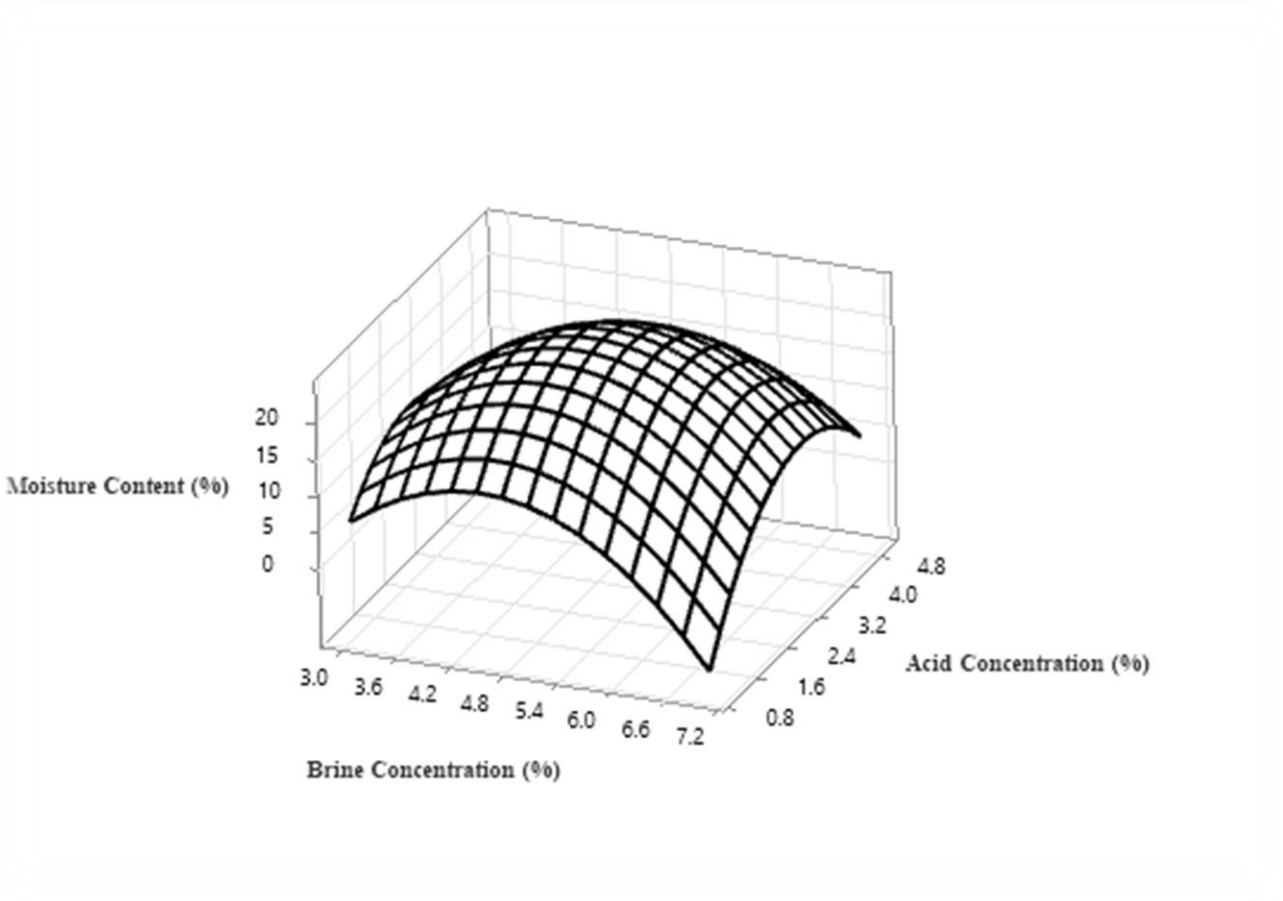


Figure 4.21: Surface Plot Of Moisture Content (%) vs Acid Concentration (%), Brine Concentration (%)

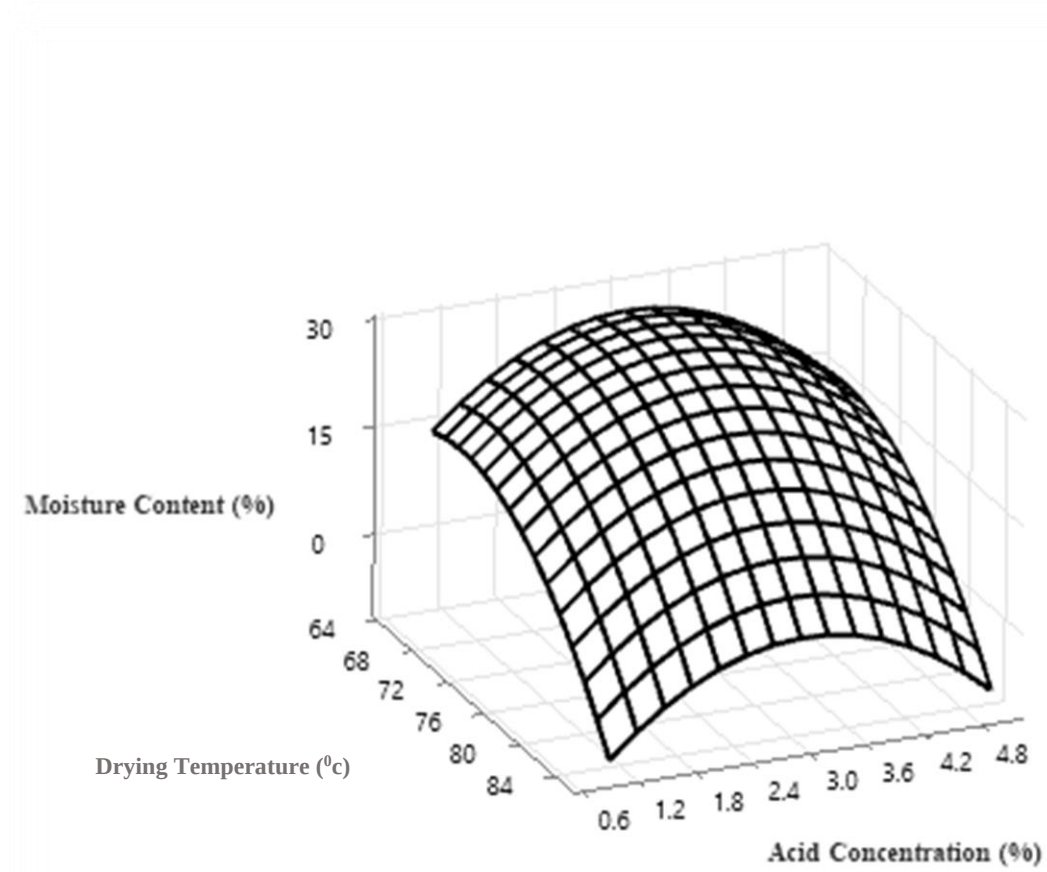


Figure 4.22: Surface Plot Of Moisture Content (%) vs Acid Concentration (%), Drying Temperature (^{0}c)

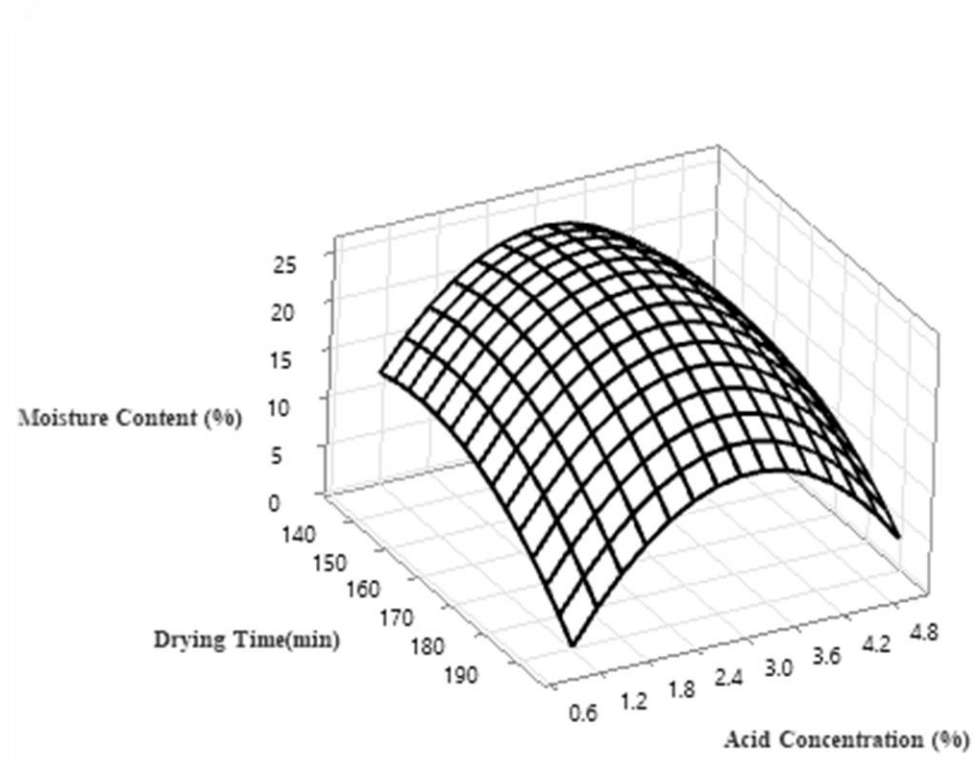


Figure 4.23: Surface Plot Of Moisture Content (%) vs Acid Concentration (%), Drying Time (min)

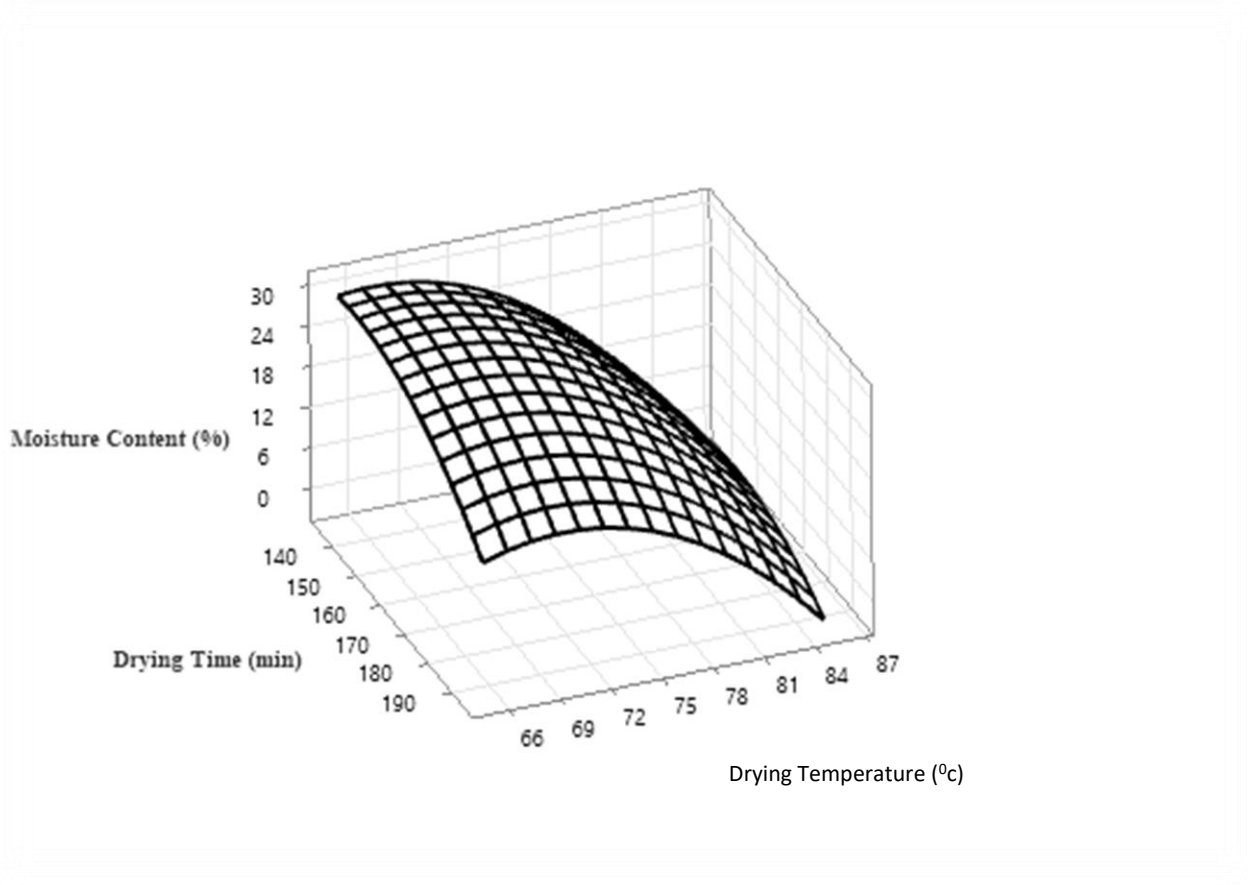


Figure 4.24: Surface Plot of Moisture Content (%) vs Drying Temperature (^{0}c), Drying Time (min)

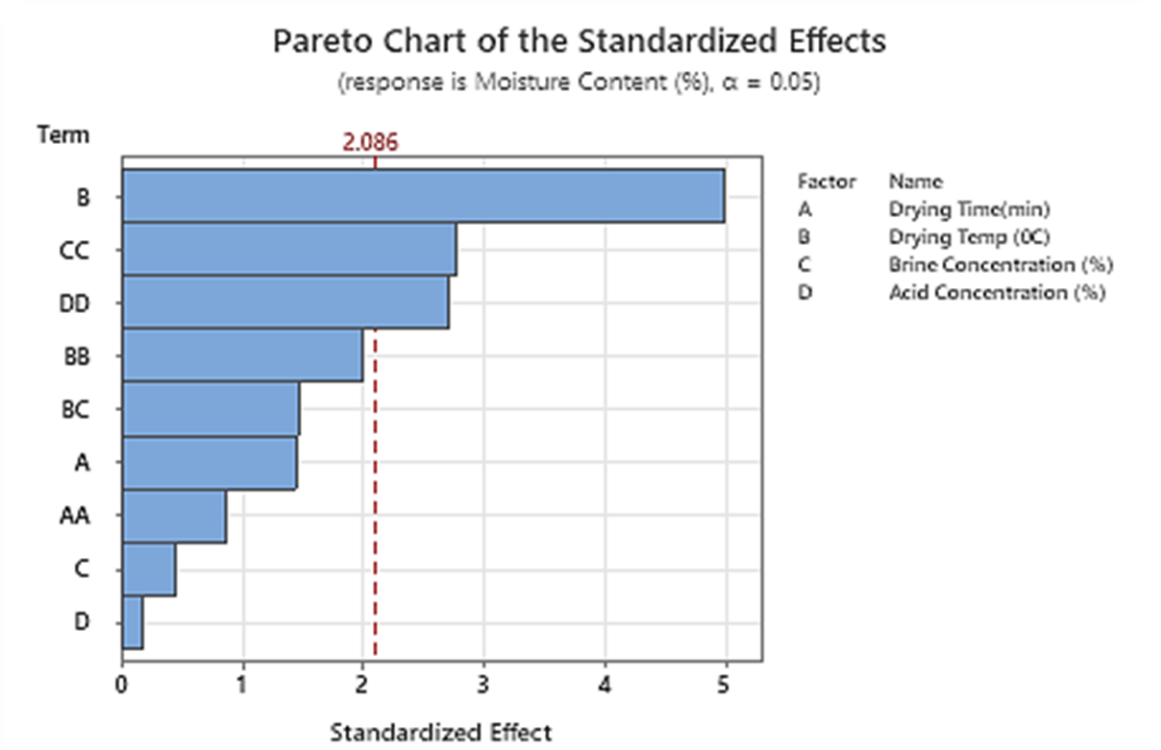


Figure 4.25: Pareto Chart of the Standardized Effects.

4.8 Model Verification

Drying experiments were conducted at the optimum drying process condition (i.e. at Drying Temperature = 80.24^0c; Salt Concentration = 6.04%; Acid Concentration = 2.26%) for 185 minutes for testing the adequacy of the model equation for predicting the response values. As a result, it was observed that the experimental values were very close to the predicted values for moisture content. Therefore, it is deduced from the above discussion that the model is adequate to assess the drying behaviour of Blue Whiting Fish.

4.9 Effect of Working Parameters on Shelf Life

a. Effect of Salt Concentration

The effect of salt concentration on the shelf life of the derived product was investigated, keeping all other parameters constant and varying the salt concentration. Figure 4.26 shows the extent of spoilage of a sample taken from Run 13, seven days after preparation. Low level of spoilage was observed showing relatively good shelf life. Figure 4.27 shows the extent of spoilage of a sample taken from Run 11 after seven days. A greater degree of spoilage is observed relative to Run 13. This can be attributed to the lower salt concentration of the brine used in its preparation (3%) compared to that of Run 13 (7%).

It is thus evident that despite the fairly similar moisture content of both samples, the shelf life of the improved with increased salt concentration.

b. Effect of Acid Concentration

Samples prepared with varying concentrations of Propionic Acid were analysed. Although the shelf life of these samples were similar, samples prepared with lower concentration of acid possessed a strong fishy odour compared to those of higher concentration.

c. Effect of Drying Time and Drying Temperature

Drying Time and Temperature were observed to directly affect only the moisture content of the products. Samples subjected to higher temperatures or longer drying times had lower moisture content and harder texture. This significantly improved the shelf life of the resulting product. Drying Temperature had the greatest effect on moisture content.

Figure 4.26: Run 13 sample after one week

Figure 4.27: Run 11 sample after one week

CHAPTER FIVE

CONCLUSION

5.1 Conclusion

It was concluded from this study that the drying temperature and drying time were the most pronounced factors affecting the moisture content of Blue Whiting fish fillets during the electrical oven drying process, followed by salt concentration and acid concentration. Response surface methodology effectively optimized the drying process parameters for the drying process of the different sizes of Blue Whiting fish in an oven. Analysis of variance has it that the effects of the drying process variables were statistically significant. A second-order polynomial model was obtained for predicting the moisture content. The optimal conditions for minimum moisture loss correspond to a temperature of 80.24^0C, Acid concentration of 2.26%, salt concentration of 6.04% and drying time of 185 min., in order to obtain moisture content of 3.115% w.b. This result has desirability of 0.9774.

Also, modelling of thin layer dryer in this study was used to model the drying process blue whiting fillets in the forced convection dryer. Three models were used to describe changes in moisture content characteristics in both drying methods. Logarithmic model was judged to be the best model for moisture ratio prediction at 60^{o}C with a correlation coefficient (X^2) $1.8x10^{-4}$ and RMSE of $1.24x10^{-2}$. Page model was judged the most appropriate for the description of experimental kinetic data at all subsequent temperatures (70^{o}C, 80^{o}C, 90^{o}C, 100^{o}C) with a correlation coefficient (X^2)

of $1.08x10^{-4}$, $1.71x10^{-4}$, $6.8x10^{-5}$, $1.14x10^{-5}$ and a R.M.S.E of $9.86x10^{-6}$, $1.24x10^{-2}$, $7.83x10^{-3}$, $3.2x10^{-3}$ respectively.

Effective moisture diffusivity ranged from 3.6565×10^{-11} to 6.994×10^{-11} is calculated using the Fick's second law (slope method). With the increase of the drying temperature and at constant hot air velocity, the effective moisture diffusivities D_{eff} increased.

REFERENCES

Abbas, K. A., Saleh A. M. (2009). The relationship between water activity and fish spoilage during cold storage:A review. *Journal of Food, Agriculture & Environment,* Vol.7 (3&4) : 86-90. 2009.

Arslan, D. and Ozcan, M. (2010). Study the effect of sun, oven and microwave drying on quality of onion slices. *Food Science and Technology*, 43, 1121-1127.

Adebowale, B.A., Dongo, L.N., Jayeola, C.O and Orisajo, S.B (2008). Comparative quality assessment of fish (Clarias gariepnius) smoked with cocoa pod husk and three other different smoking materials. *Journal of Food Technology,* 6: 5-8.

Aghbashlo M., Kianmehr M.H., Samimi-Akhijahani H., Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thinlayer drying of berberis fruit (Berberidaceae*). Energy Convers. Manage*., 2008, 49, 2865–2871

Agrawal, Y. C., and R. P Singh. 1977. "Thin layer drying studieson short grain rough rice." ASAE paper No: 3531.

Akpinar, E.K., Bicer, Y. and Yildiz, C. (2003). Thin layer drying of red pepper. *Journal of Food Engineering*, 59: 99-104

Amos, B (2007). Analysis of quality deterioration at critical steps/points in fish handling in Uganda and Iceland and suggestions for improvement. United Nations University, Uganda. P. 45.

Ashie INA, Smith JP, Simpson BK. (1996) Spoilage and shelf–life extension of fresh fish and shellfish. *Crit Rev in Food Sci and Nutr*.,36(1–2):87– 121

Bailey, R. S. (1982). "The population biology of blue whiting in the North Atlantic". *Advances in Marine Biology*. **19**: 257 -355

Brooker, D.B; F.W Bakker-Arkema and C.W. Hall. (1992). Drying and storage of Grains and Oil Seeds. The Avi publishing Company, Inc. Westport, Connecticut.

Bruce D.M., (1985) Exposed-layer barley drying, three models fitted to new data up to 150°C. *J. Agric. Eng. Res*., 32, 337–348.

Demir, V., Gunhan, T., Yagcioglu, A.K. and Degirmencioglu, A. (2004) Mathematical Modeling and the Determination of Some Quality Parameters of Air Dried Bay Leaves. *Biosystems Engineering*, *88, 429-437*.

Demir, V., T. Gunhan, A.K. Yagcioglu, and N Degirmencioglu. 2004. "Mathematical modeling and determination of some quality parameters of air-dried bay leaves." *Biochemistry Engineering* 88(3): 225-235.

Doymaz, İ. (2008). Convective drying kinetics of strawberry. *Chemical Engineering and Processing: Process Intensification*, 47, 914–919.

Jain D., Pathare B. P. (2007). "Study of the drying kinetics of open sun drying of fish." *Journal of Food Engineering 78* 1315-1319.

Doungporn S., Poomsa-ad N., Wiset L., Drying equations of Thai Hom Mali paddy by using hot air, carbon dioxide and nitrogen gases as drying media. *Food Bioprod. Process*., 2012, 90, 187–198.

El-Beltagy, A., Gamea, G. R., & Essa, A. H. (2007). Solar drying characteristics of strawberry. Journal of Food Engineering, 78, 456–464.

Ertekin, C., & Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. Journal of Food Engineering, 63(3), 349–359. https://doi.org/10.1016/j.jfoodeng.2003.08.007.

FAO., 2005. Post-harvest changes in fish. In: FAO Fisheries and Aquaculture Department, Food and Agriculture Organization, Rome, Italy. http://www.fao.org/fishery/topic/12320/en0

Fisheries Committee for the West Central Gulf of Guinea (FCWC). *Nigeria Fishery Statistics – 2016 Summary Report*, 2016. https://fcwc-fish.org/uncategorized/nigeria-fishery-statistics-2016-summary-report

Fellows, P. and Hamptum (1992).Small-scale food processing. *'A guide for appropriate equipment'.*

Food and Agriculture Organization (FAO). *Global per capita fish consumption rises above 20 kilograms a year. Italy;* 2016.

Frankel, E.N. 2005. Lipid Oxidation, Second Edition, The Oily Press, Bridgwater, England.

Fraser, O. and Sumar, S (2008). Compositional changes and spoilage in fish. Nutrition of Food Science, 5: 275-279.

Gram L, Huss HH. Microbiological spoilage of fish and fish products. *Int J of Food Microbiol.* 1996;33(1):121–137.

Gram, L. and Huss, H.H (2000). Fresh and Processed Fish and Shellfish. In: *The Microbiological Safety and Quality of Foods,* 472-506.

Hansen, T.L., Gill, T., Rontved, S.D and Huss, H.H (2003). Importance of autolysis and microbiological activity on quality of cold-smoked salmon. *Food Res International*, 29: 181-186.

Hassan AM, Al-Hakim SH (1985) *Food Processing Part I*, Baghdad Press, University of Baghdad

Huis, T and Veld, J.H.J (2006). Microbial and biochemical spoilage of foods: An overview. International Journal of Food Microbiology, 33:1-18.

Hultin, H.O (2004). Oxidation of Lipids in Seafoods. In: Seafoods Chemistry, Processing Technology and Quality, Shahidi, F. and J.R. Botta (Eds.)., 1st Edn., Blackie Academic and Professional, London, UK, pp. 49-74.

Henderson S.M., Progress in developing the thin layer drying equation. Transactions of ASAE, 1974, 17, 1167–1172

Henderson, S.M. (1974) Progress in Developing the Thin Layer Drying Equation. *Transactions of the American Society of Agricultural Engineers,* 17, 1167-1172. https://doi.org/10.13031/2013.37052

Henderson S.M., Pabis S., Grain drying theory. II. Temperature effects on drying coefficients. J. Agric. Eng. Res., 1961, 6, 169–174

Ikrang, Elijah G, Okoko, Joseph U, Okoko Joseph, Mfrekemfon S.1 Obot, and C. O Akubuo. (2014). "Modeling of Thin Layer Drying Kinetics of Salted Fish Fillets (Tilapia Zilli) in a Direct Passive Solar Dryer." *IOSR Journal Of Environmental Science, Toxicology And Food Technology (IOSR-JESTFT)* 16-24.

J. Jackson. (2018). Multivariate Techniques: Advantages and Disadvantages, https://www.theclassroom.com/multivariate-techniques-advantagesdisadvantages-8247893.ht

J.H. Perry, Chemical Engineering Handbook, 2007, 8th ed., McGraw-Hill, New York, 2007, pp. 28.

Karathanos, V. T., & Belessiotis, V. G. (1999). Application of a thin-layer equation to drying data of fresh and semi-dried fruits. *Journal of Agricultural Engineering Research*, *74*(4), 355-361.

Khayat, A. and Schwall, D (2003). Lipid oxidation in seafood. Food Technology, 37: 130-140.

Koo, I., (2020) *Using Salt as a food preservative*, https://www.verywellhealth.com/ eat-it-with-a-grain-of-salt-1958878.

Lomauro, C.J., A.S. Bakshi, and T.P Labuza. (1985),. "Moisture transfer properties of dry and semimoist foods." *J. Food Sci.* 50, 397–400.

M.A, Tutuncu, and Labuza T.P. (1996). "Effect of geometry on the effective moisture transfer diffusion coefficient." *J. Food Eng* 30, 433–447.

Madamba, P.S.; R.H., Driscoll and K.A., Buckle. (1996). The thin layer drying characteristic of garlic slices. *Journal of Food Engineering*, 59: 57- 97.

Menzies, D. J., & O'Callaghan, J. R. (1971). The effect of temperature on the drying rate of grass. *Journal of Agricultural Engineering Research*, *16*(3), 213-222.

Murray J, Burt JR. The composition of fish. In: Huss HH editor. *Quality and quality changes in fresh fish*. Italy:FAO Fisheries Technical Paper no 348; 1969.

Oueslati, Hatem & Mabrouk, S. & Mami, Abdelkader. (2012). System Design, Mathematical Modelling and Simulation of Process Drying in a Solar-Gas Convective Tunnel Dryer. *International Journal of Scientific and Engineering Research.* 3

Ozdemir, M., and Y. O Devres. 1999. "The thin layer drying characteristics of hazelnuts during roasting." *Journal of Food Engineering.* 42, 225-233.

Page G.E. (s1949). Factors influencing the maximum rates of air drying shelled corn in thin layers. M.S. Thesis. Department of Mechanical Engineering, Purdue University, Purdue, USA.

Pangavhane, D. R., R. L. Sawhney, and P. N Saravadia. (1999). "Effect of various dipping pre-treatment on drying kinetics of Thompson seedless grapes. ." *Journal of Food Engineering.* 39, 211-216

Poulter NH, Nicolaides L. (1985). Studies of the iced storage characteristics and composition of a variety of Bolivian freshwater fish. 1. Altiplano fish. In: Huss HH editor. *International journal of Food science & technology*. 20(4):437–449.

Poulter NH, Nicolaides L. (1985). Studies of the iced storage characteristics and composition of a variety of Bolivian freshwater fish. 2. Parana and Amazon Basins fish. In: Huss HH editor. *International journal of Food science & technology*. 20(4):451–465.

Rafiee S., Sharifi M., Keyhani A., Omid M., Jafari A., Mohtasebi S.S., et al., Modeling effective moisture diffusivity of orange slices (Thompson Cv.). Int. J. Food Prop., 2010.

Sagar V. R., Suresh Kumar P., "Recent advances in drying and dehydration of fruits and vegetables: a review." *Journal of Food Science and Technology*. 2010 Jan; 47(1): 15–26.

Shitanda D., Wanjala N.V. (2006) Effect of different drying methods on the quality of jute (*Corchorus olitorius L*.). *Drying Technology*, 24, 95–98.

Togrul, I.T, and 'D. Pehlivan. (2003). "Mathematical modeling of drying kinetics of single apricot." *Journal of Food Engineering 58* 23-32.

Togrul, I.T., and . Pehlivan D. (2002). "Mathematical Modelling of solar drying of apricots in thin layers." *Journal of Food Engineering 55:* 209-216.

Wang C.Y., Singh R.P. (1978). Use of variable equilibrium moisture content in modeling rice drying. Transactions of ASAE, 11, 668–672

Yaldiz, O, C Ertekin, and H. I Uzan. (2001). "mathematical modelling of thin layer solar drying of Sultana grap." *Energy,* 26, 457-465.

Yaldiz, O., and C. Ertekin. (2001). "Thin layer solar drying of some vegetables." *Drying Technology. 19* 583-596.

M. Zielinska and M. Markowski,. (2010). “Air Drying Characteristics and Moisture Diffusivity of Carrots,” *Chemical Engineering and Processing: Process Intensification,*49(2), 212-218. doi:10.1016/j.cep.2009.12.005

Zogzas N.P., Maroulis Z.B., Marinos-Kouris D. (1996). Moisture diffusivity data compilation in foodstuffs. *Drying Technology*, 14, 2225–2253.

APPENDIX A

TABLE OF RESULTS FOR DRYING KINETICS EXPERIMENT

Table A1 Drying at 60 ^{o}C (initial mass: 50 g)

Time (Min)	Moisture Content (Wb)	Moisture Content (Db)	Moisture Ratio (Mr)
0	0.805	4.128	1.000
15	0.690	2.226	0.539
25	0.622	1.643	0.398
35	0.543	1.190	0.288
45	0.480	0.923	0.224
55	0.425	0.739	0.179
65	0.368	0.583	0.141
75	0.337	0.508	0.123
85	0.313	0.456	0.111
95	0.288	0.405	0.098
105	0.267	0.364	0.088
115	0.250	0.333	0.081
125	0.230	0.299	0.072
135	0.218	0.279	0.068
145	0.200	0.250	0.061
155	0.188	0.232	0.056
165	0.178	0.217	0.053
175	0.170	0.205	0.050
180	0.162	0.193	0.047

Table A2: Drying at 70 ^{o}C (initial mass: 50 g)

Time (Min)	Moisture Content (Wb)	Moisture Content (Db)	Moisture Ratio (Mr)
0	0.792	3.808	1.000
10	0.718	2.546	0.669
20	0.648	1.841	0.483
30	0.584	1.404	0.369
40	0.530	1.128	0.296
50	0.480	0.923	0.242
60	0.434	0.767	0.201
70	0.392	0.645	0.169
80	0.348	0.534	0.140
90	0.318	0.466	0.122
100	0.288	0.404	0.106
110	0.264	0.359	0.094
120	0.240	0.316	0.083
130	0.220	0.282	0.074
140	0.200	0.250	0.066
150	0.184	0.225	0.059
160	0.172	0.208	0.055
170	0.160	0.190	0.050
180	0.148	0.174	0.046

Table A3: Drying at 80 ^{o}C (initial mass: 50 g)

Time (Min)	Moisture Content (Wb)	Moisture Content (Db)	Moisture Ratio (Mr)
0	0.792	3.808	1.000
10	0.722	2.597	0.682
20	0.632	1.717	0.451
30	0.556	1.252	0.329
40	0.502	1.008	0.265
50	0.442	0.792	0.208
60	0.388	0.634	0.166
70	0.338	0.511	0.134
80	0.294	0.416	0.109
90	0.254	0.340	0.089
100	0.220	0.282	0.074
110	0.192	0.238	0.062
120	0.168	0.202	0.053
130	0.150	0.176	0.046
140	0.134	0.155	0.041
150	0.118	0.134	0.035
160	0.108	0.121	0.032
170	0.094	0.104	0.027
180	0.084	0.092	0.024

Table A4: Drying at 90 ^{o}C (initial mass: 50 g)

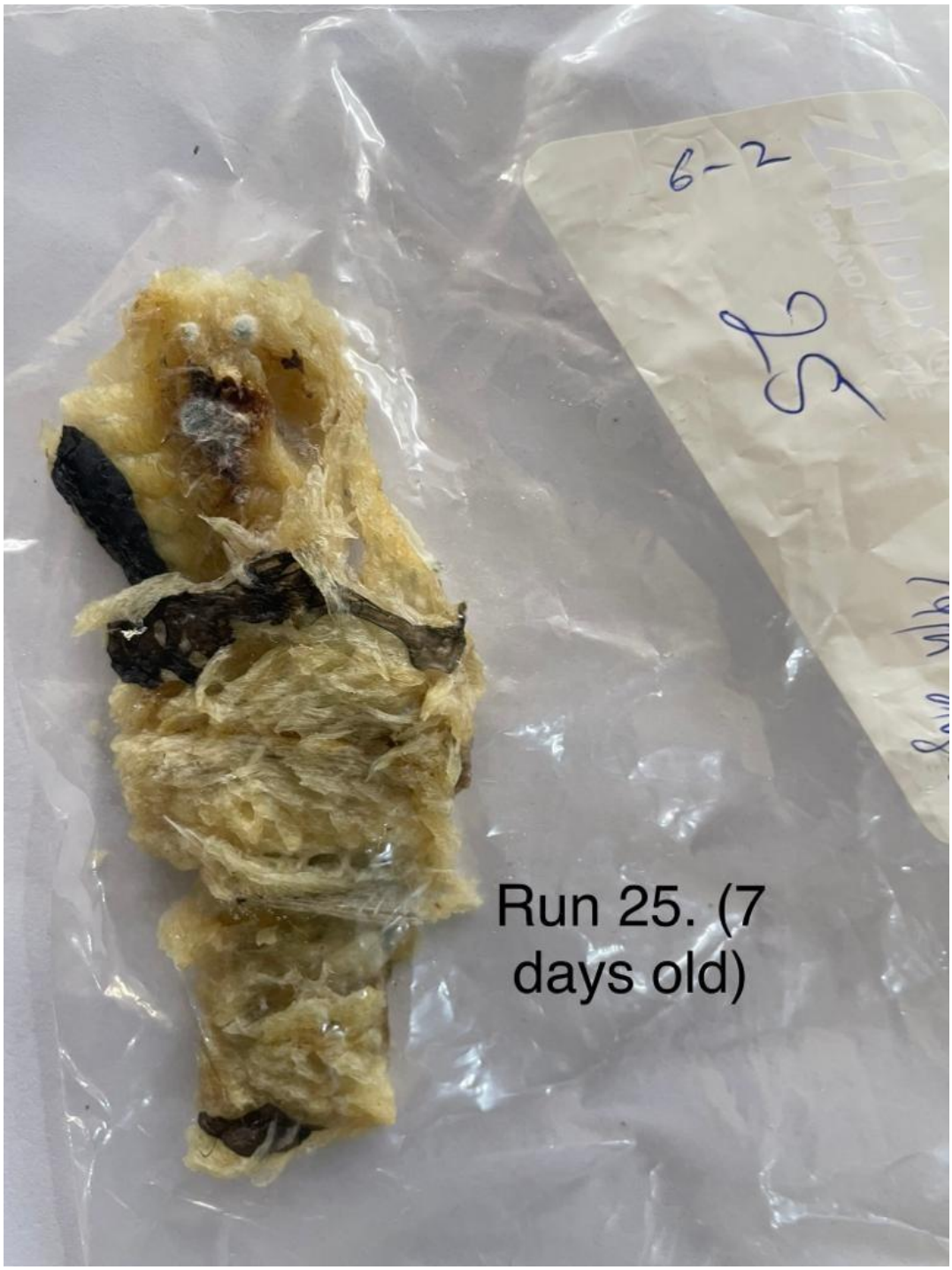
Time (Min)	Moisture Content (Wb)	Moisture Content (Db)	Moisture Ratio (Mr)
0	0.812	4.319	1.000
10	0.690	2.226	0.515
20	0.578	1.370	0.317
30	0.488	0.953	0.221
40	0.410	0.695	0.161
50	0.346	0.529	0.122
60	0.296	0.420	0.097
70	0.250	0.333	0.077
80	0.214	0.272	0.063
90	0.186	0.229	0.053
100	0.160	0.190	0.044
110	0.142	0.166	0.038
120	0.124	0.142	0.033
130	0.108	0.121	0.028
140	0.096	0.106	0.025
150	0.086	0.094	0.022
160	0.074	0.080	0.019
170	0.066	0.071	0.016
180	0.050	0.053	0.012

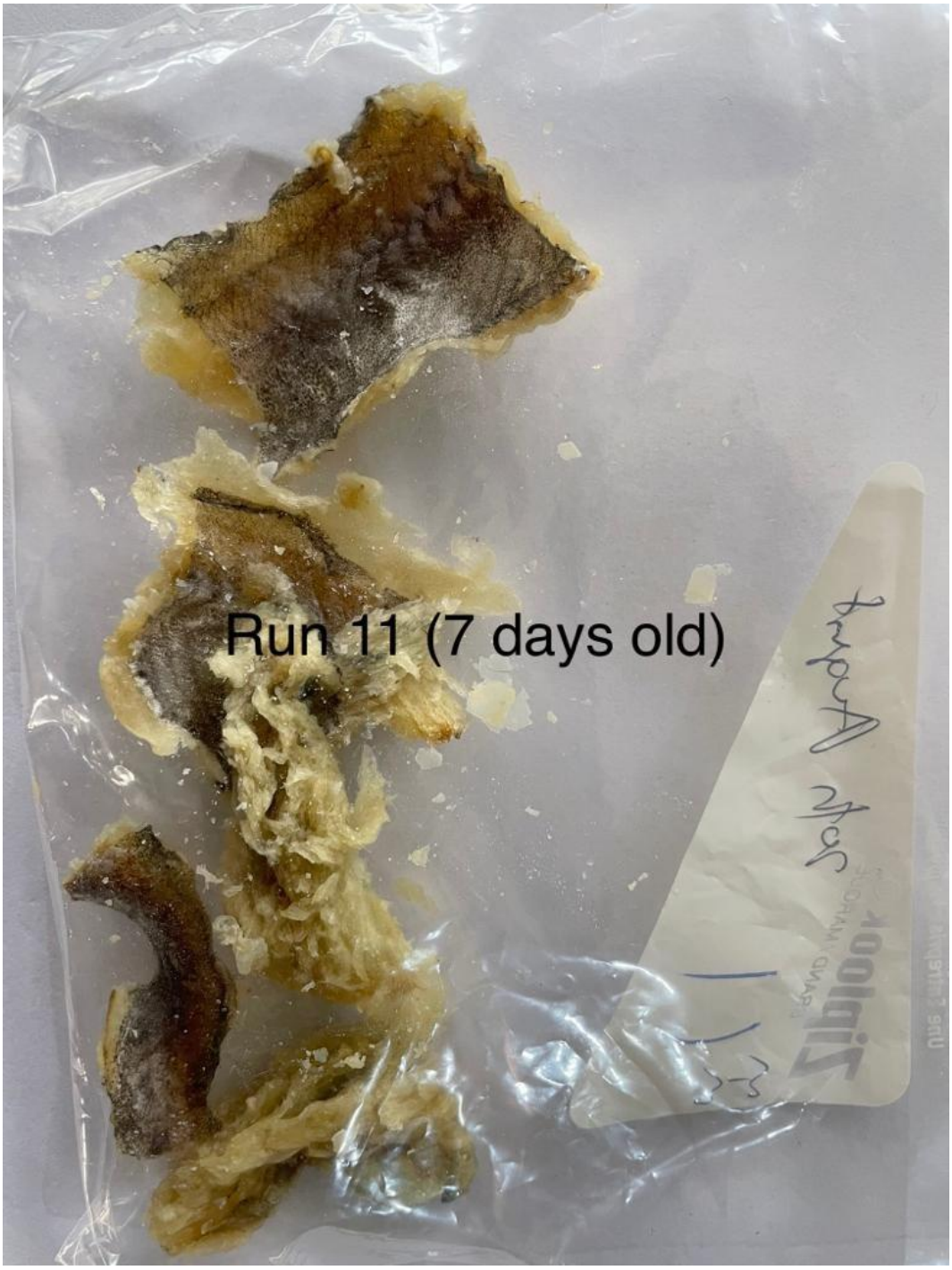
Table A5: Drying at 100 ^{o}C (initial mass: 50 g)

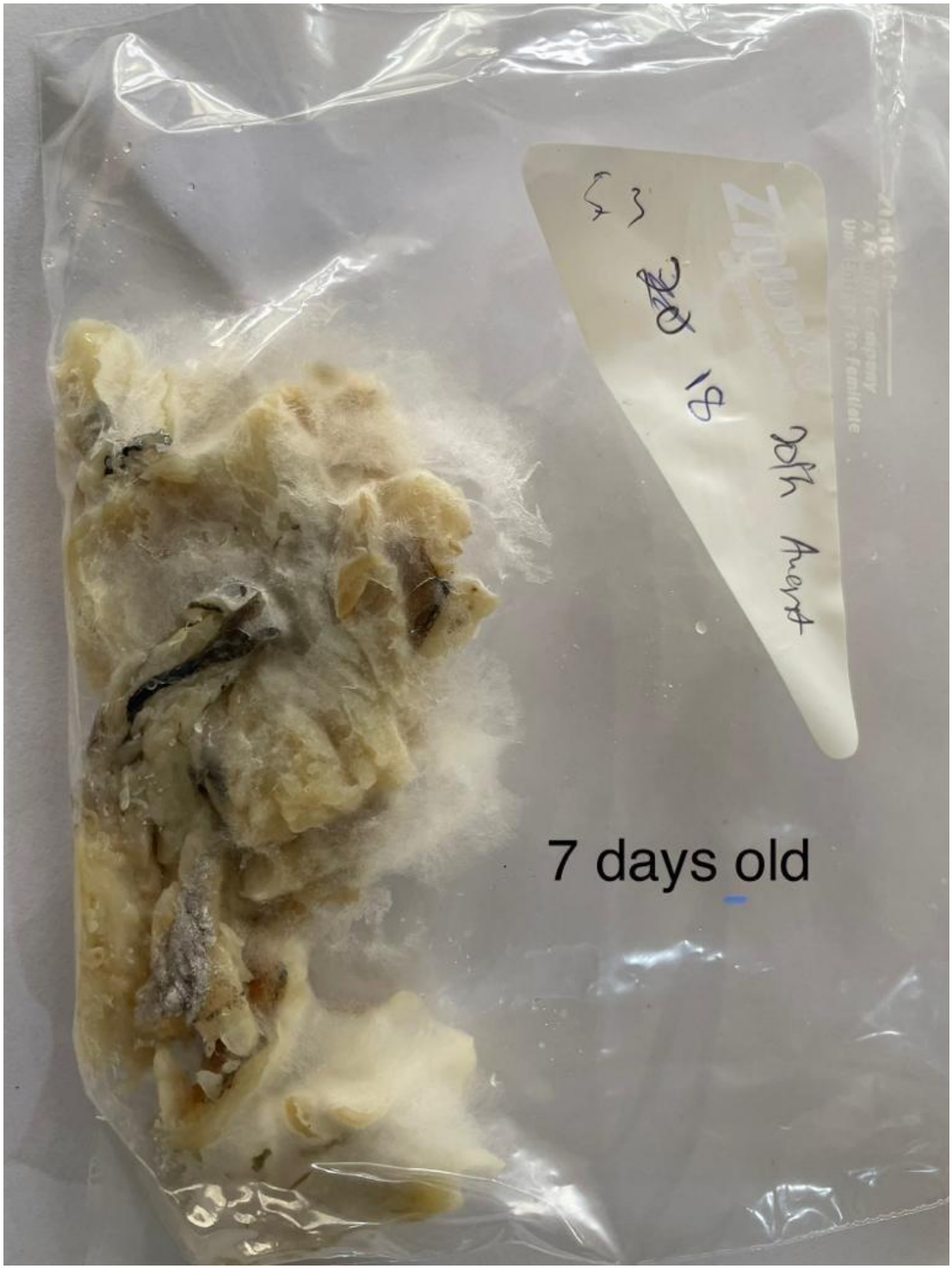
Time (Min)	Moisture Content (Wb)	Moisture Content (Db)	Moisture Ratio (Mr)
0	0.812	3.717	1.000
10	0.690	1.857	0.500
20	0.578	1.119	0.301
30	0.488	0.736	0.198
40	0.410	0.502	0.135
50	0.346	0.355	0.096
60	0.296	0.256	0.069
70	0.250	0.196	0.053
80	0.214	0.149	0.040
90	0.186	0.116	0.031
100	0.160	0.089	0.024
110	0.142	0.068	0.018
120	0.124	0.055	0.015
130	0.108	0.042	0.011
140	0.096	0.033	0.009
150	0.086	0.029	0.008
160	0.074	0.022	0.006
170	0.066	0.016	0.004
180	0.050	0.012	0.003

APPENDIX B

Photos Showing Extent Of Spoilage In Various Samples After One Week

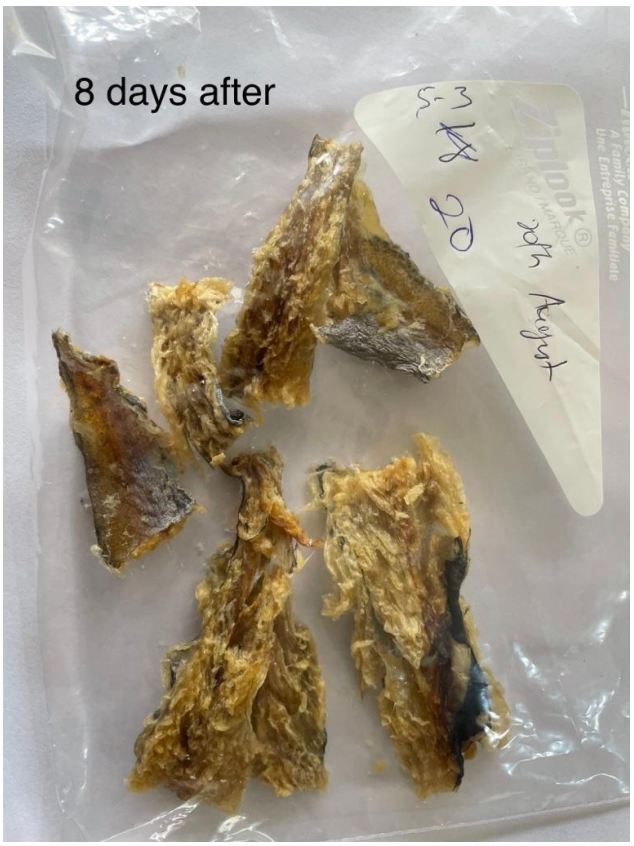



Run 11 (7 days old)


7 days old


8 days old


8 days old


8 days after


Run 21. 8 days old


8
8/8/2021
8 days old


A Family Company
Une Entreprise Familiale
Ziploc
BRAND MARQUE
28
8 days old