2022-07

EFFECT OF ETHYL OLEATE PRETREATMENT ON OVEN DRYING OF GELILA TOMATOES

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SCHOOL OF RESEARCH AND POST GRADUATE STUDIES

MASTER'S PROGRAM IN PROCESS ENGINEERING

THESIS TITLE: EFFECT OF ETHYL OLEATE PRETREATMENT ON OVEN DRYING OF GELILA TOMATOES

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Bahir Dar, Ethiopia

July, 2022

BAHIR DAR UNIVERSITY

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FACULTY OF CHEMICAL AND FOOD ENGINEERING

Effect of ethyl oleate pretreatment on oven drying Gelila tomatoes

By:

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A partial fulfillment of the requirements for the degree of Master of Science in Process Engineering

Advisor : Solomon Workneh (PhD)

Bahir Dar, Ethiopia

July, 2022

DECLARATION

This is to certify that the thesis entitled **"Effect of ethyl oleate pretreatment on oven drying of Gelila tomatoes"**, submitted in partial fulfillment of the requirements for the degree of Master of Science in process engineering under faculty of chemical and food engineering, Bahir Dar Institute of Technology, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during this investigation have been duly acknowledged.

Molla Zegeye Belay	___________	23/11/2014 E.C
Name of the Candidate	Signature	Date

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Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

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As members of the board of examiners, we examined this thesis entitled" Effect of ethyl oleate pretreatment on oven drying of Gelila tomatoes" by Molla Zegeye. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Masters of Science in "Process Engineering".

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ACKNOWLEDGMENT

First of all, may Jesus Christ, the son of the Virgin Mary, not only protect me from all evil but also glorify and glorify me for what I have done. Next, I wish to give a sincere thank you to my advisor whom I respect with all my heart, Dr. Solomon Workneh for his scientific guidance and valuable discussions. He has been continuously encouraging and motivating me throughout my thesis work. Second, I never forget the special support, love, and follow-up from my family and my lovely wife Zewditu Zinabie, in all the words I describe thank you; you have done so much for me.

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LIST OF ABBREVIATIONS

Conc.	Concentration
$CuSO_4$	Copper sulphate
D_{eff}	Effective diffusivity
DR	Drying rate
Ea	Activation energy
EO	Ethyl oleate
FAO	Food association organization
H_3BO_3	Boric acid
HCl	Hydrochloric acid
HPO_3	Methaphosphoric acid
H_2SO_4	Sulfuric acid
K mt	Kilo metric tone
K_2SO_4	Potassium salfate
MC	Moisture content
MoI	Ministry of irrigation
MR	Moisture ratio
NaOH	Sodium hydroxide
NH_3	Ammonia
RMSE	Root mean square error
SSE	Sum of square error
χ^2	Coefficient of determination

ABSTRACT

Postharvest losses of tomatoes have been estimated to be more than 40%. Drying tomatoes using the appropriate dryer and condition to the optimum storage moisture content minimizes the postharvest loss. It has been reported that drying tomatoes using an oven dryer increases the drying rate and minimizes the adverse effects of unpredictable conditions during the drying stage. However, an Oven dryer is one of the promising and sustainable alternatives for the drying of tomatoes. It has negative quality effects because of a longer drying time and high energy consumption. The main objective of this study was to study the effect of ethyl oleate pretreatment on oven drying tomatoes. Chemical pretreatment like ethyl oleate can accelerate the drying tomatoes by dipping, resulting in a break-down of the waxy cuticular surface of the tomato which leads to reducing the resistance to moisture content without affecting the flavor of the final product. This study investigates the effect of ethyl oleate pretreatment on oven drying characteristics and quality of tomatoes. An oven dryer with a temperature of 50℃, 60℃, and 70℃ was used. The process used 2%, 4%, and 6% concentrations of ethyl oleate, and dipping times of 5, 10 and15 minutes. The performance was tested using a sample load of 600gm of tomatoes. The experimental data were fitted to ten different thin-layer drying models and the goodness of fit for each model was evaluated using R^2*, sum square error, and root mean square error. The modified page I model gave a better prediction of tomatoes drying in an oven dryer. Response Surface Methodology was used to optimize drying parameters such as temperature (50-70℃), dipping time (5-15 min), and ethyl oleate concentration (2-6 %v/v). An optimum drying rate of 228.452gm/hr was obtained at dipping time 10.19 min, ethyl oleate concentration 4.14%v/v, and drying temperature of 69.92 ℃. Meanwhile, a maximum drying rate of 228gm/hr was obtained from the experimental result, which shows the reliability of the predicted quadratic model. The study clearly showed that tomatoes drying in the pretreatment of ethyl oleate in an oven dryer will help growers to reduce the drying time, protect from contamination, and ultimately gives more quality dried products and reduce postharvest loss of tomatoes.*

Key words: *Postharvest loss, Drying, Tomatoes, Ethyl oleate, Oven dryer, drying models*

1. INTRODUCTION

1.1 Background

Tomato is among the foremost profoundly consumed and well-known fruits within the world (Hanson et al., 2004). Nutritiously, tomatoes are wealthy sources of antioxidant compounds such as β- carotene, lycopene, ascorbic corrosive, and phenolic compounds (Mwende et al.,2018). Tomato is a climacteric crop and intrinsically perishable, with a shelf life of 8 to 12 days in its fresh state after the harvest. Tomato after harvest losses have been estimated to be as high as 50%. These losses translate to a subsequent imbalance in supply and demand and consequential losses in income to both small and large scale farmers (Mwende et al., 2018). After harvesting tomatoes preservation strategies are required to expand the commodity's shelf life. One of such methods is drying which lowers the moisture content and consequently the water activity of food to a level that does not support bacterial and mold growth (Md Saleh et al., 2020).

Drying is an operation that permits the extraction of moisture from an item to reach the moisture conservation of the product. This can be a strategy that a few authors propose for the preservation of tomatoes (Dianda et al., 2015). Conventional oven drying is one of the drying mechanisms in which heat is transferred from the surface to the insides of the material. This pressure is generated between the surface and interior due to evaporation, such that the interior moisture is driven out and evaporation continues on the surface. Oven drying has low energy efficiency with negative quality effects, and it takes a longer drying time to dry food when compared with other dryers (freeze-drying, microwave drying, and vacuum drying). Thus, if we want to dry a product by using an oven dryer, we must take measures that could have improved the quality of the product (Huang, 2013).

Tomatoes are usually subjected to physical or chemical pretreatment before drying to shorten the drying time, decrease the energy consumption and preserve the quality of products (Yu et al., 2018). The drying rate and the quality of the products have to a large extent related to the pretreatments that are carried out before drying (Fernandes et al., 2011). For the most part, agro products drying is a time and energy-consuming process, pretreatment effectively enhances the drying process. Some studies have confirmed that soaking in a chemical additive solution, such as sodium hydroxide, ethyl or methyl oleate emulsions dissolve the wax layer, and therefore increases the drying rate (Deng et al., 2019). Bleaching improves drying rates due to softening of the structure and destruction of the cell wall, leading to lower resistance to moisture movement during drying which reduced drying time for sour cherries from 61.83% to 74.73% (Deng et al., 2019). As a result, there is a need to enhance the rate of drying to ensure maximum retention of antioxidant molecules in tomatoes as well as to reduce oxidation, enzymatic, and isomerization reactions thus protecting these molecules from degradation. Since color, lycopene, and total phenolic content in tomatoes are regarded as good quality indicators of the drying process reducing the quality degradation of these indicators to a minimum is paramount (Hashib et al., 2015). Therefore, the main objective of this thesis is to investigate the effect of ethyl oleate pretreatment on the drying characteristics and quality of tomatoes. The dried tomato slices could decrease the postharvest losses, increase the availability of tomatoes over an extended period, stabilize the price during the glut season and keep the nutritive value of the tomatoes.

1.2 Statement of the Problem

The postharvest supply chain of tomatoes involves harvesting, transportation, storage, and preparing end-user that is selling. The magnitude of tomatoes losses during harvesting and storage are the highest in the entire postharvest supply chain of tomatoes. However, after harvesting the shelf life of the tomato is 7 to 12 days, and also losses of fruits like a tomato can reach as high as 40 to 50% in the tropics and sub-tropics (Md Saleh et al., 2020). These losses can be caused by the perishable nature of production and market conditions and the absence of cost-effective and appropriate post-harvest technologies. Therefore, adequate drying of tomatoes is important to prevent postharvest losses, as well as for maintaining its quality. The use of appropriate drying methods can minimize the quantitative, qualitative, and nutritional losses of tomato fruit. The traditional practice of drying techniques of tomato fruits is exposed to unfavorable weather conditions (high relative humidity and rainy conditions) and the fruit will not be dried sufficiently if weather conditions are too cloudy and humid and this can result in high postharvest losses. Additionally, over-drying or delays in the drying process, animals feeding on the fruit, spillage and non-uniform drying, incomplete drying, and fungal propagation are the drawbacks of open sun drying. The degree of the problems shows that there is a need to understand the drying characteristics and select the correct drying system for the drying of tomatoes. Oven dryer is one of the alternatives drying tomatoes; it has good drying performance and environmental benefits in the drying of threshed tomatoes (Balladin & Headley, June 0887). Oven drying has negative quality effects because of a longer drying time (Inyang et al., 2017). Longer drying time results in high energy consumption, degradation of nutrients, expose to more microbial, and low drying efficiency. Fast-drying reduces the risk of spoilage, improves the quality of the product, gives higher throughput, and reduces the drying time (Fernandes et al., 2011). Ethyl oleate pretreatment is the best way of increasing the rate of drying to shorten the drying time, decrease the energy consumption, and preserve the quality of products (Yu et al., 2018) and (I. Doymaz, 2007). Until now, different researchers have been done, the effects of ethyl oleate pre-treatment on oven drying of tomatoes using the mixture of ethyl oleate with an alkaline solution. Different concentration of ethyl oleate on oven drying, need to be studied and also the method was cost ineffective (Singh et al., 2008). Having this research gap, this study was to investigate the effect of ethyl oleate pre-treatment on oven drying of tomatoes using ethyl oleate with water to improve its drying characteristics and optimize the parametric conditions (dipping time, drying temperature, and ethyl oleate with water concentration) using response surface methodology.

1.3 Objectives

1.3.1 General objective

The general objective of the study is to investigate the effect of ethyl oleate pretreatment on the drying of Gelila tomatoes**.**

1.3.2 Specific objectives

The specific objective of this proposal includes:

- To determine the optimum drying condition of the process (effect of ethyl oleate concentration, dipping time, and temperature)
- To develop thin layer drying models of the tomato drying process
- To evaluate the quality of sliced dried tomato by comparing with row tomato slice using physicochemical analysis

1.4 Scope of the study

The current study focused on studying the drying effect of ethyl oleate pretreatment for tomatoes drying. The scope of this thesis was collecting tomatoes that are popular in the local area, transporting them to the experimental site, pretreating them with ethyl oleate, and drying them using an oven dryer. Data on moisture content reduction at different temperatures and physiochemical analysis were recorded continuously. The effect of ethyl oleate concentration and dipping time and drying temperature on the drying performance of oven drying was analyzed.

1.5 Significance of the study

This study was believed to be significant by contributing its role in reducing a significant level of postharvest loss and its consequence on the livelihood of the farmers. Farmers lose a considerable amount of food crops annually due to primary factors such as molding and deterioration in the quality of tomatoes. This study was on drying of tomatoes using an oven dryer; hence the tomatoes were safe from contamination with foreign matter, mechanical damage during handling, and insufficient protection during storage as well as bio-deterioration from microorganisms. As a result, society could get a year-round dry-safe tomato. This study could be useful for agricultural cooperatives. Generally, this research addressed the problems associated with the postharvest handling of tomatoes, in particular drying, by assessing the drying characteristics of tomatoes in an oven dryer which can afford. It will be helpful in the modeling, design, and performance assessment of oven dryers and can be used as a reference for oven drying applications for different agricultural products.

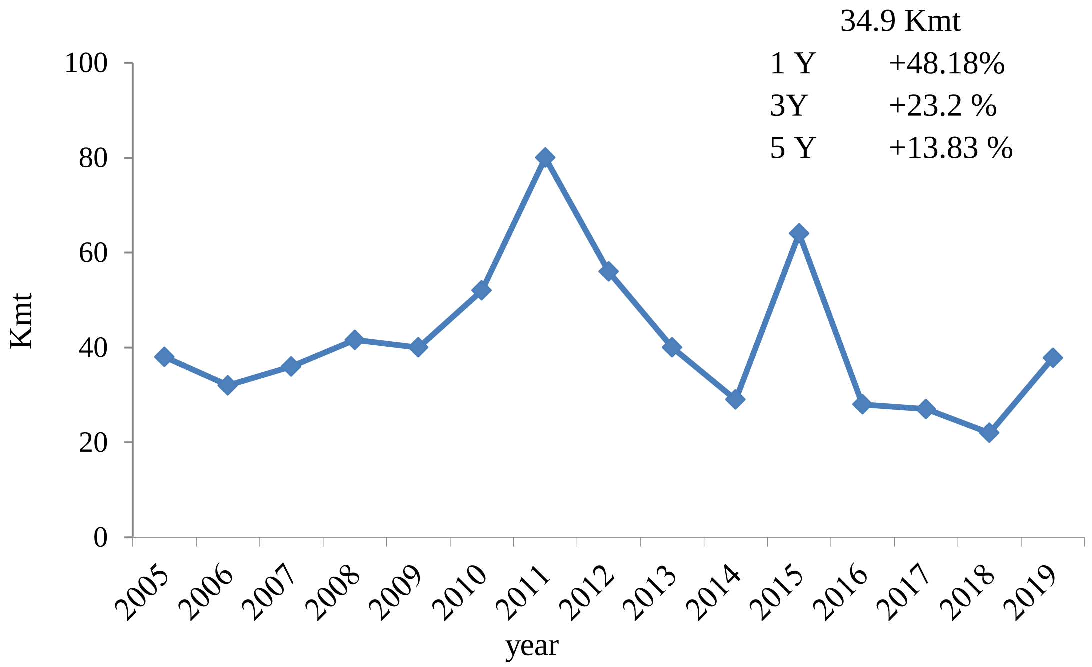
2. LITERATURE REVIEW

2.1 Tomatoes

Tomato (Lycopersicon esculentum L.) is one of the most important vegetables worldwide. World tomato production amounted to about 152.9 million tons of fresh fruit valued at $74.1 billion (FAOSTAT Database, 2009). The cultivated tomato was brought to Europe by the Spanish conquistadors in the 16th century and later introduced from Europe to South and East Asia, Africa, and the Middle East. Tomatoes contribute to a healthy, well-balanced diet. They are rich in minerals, vitamins, essential amino acids, sugars, and nutritional fiber. Tomato contains vitamin B and C, iron, and phosphorus. Tomatoes are eaten chilled in salads or cooked in sauces, soups, and meat or fish dishes (Balemi & Negisho, 2012).

Tomato is a major crop of edible and nutritious vegetables in Ethiopia. The entire annual of tomatoes in Ethiopia in 2019 was 34950 metric tons (FAO code: 0388-Tomatoes). It is cultivated in almost all home gardens and also in the field by the use of rainfall and irrigation for its adaptability to a wide range of soil and climate in Ethiopia. It is widely cultivated in tropical, subtropical, and temperate climates and thus it ranks third in terms of world vegetable production (FAO, 2006). By use and culture, the tomato is considered a vegetable. Botanically, however, it is a fruit, and among the fruits, it is a berry, because it is indecent, luscious, and has one or more seeds that are not stones (Salunkhe et al., 1974).

Ethiopia has a comparative advantage in the processing of horticultural products due to its favorable climate for the production of various fruits and vegetables. The production and processing of horticultural crops, vegetables, and fruits are given a high priority by the Government and various incentives have been provided for investors investing in this sub-sector.



Source: FAOSTAT

Figure 1 Production capacity of tomato in Ethiopia

2.2 Classification of tomatoes

Tomatoes can be classified either by fruit type or growth pattern characteristics. By fruit type, the most commonly grown types are cherry and plum (Roma). According to the U.S. Standards USDA, 1975, fresh market tomatoes are classified based on color, into six ripening stages.

Table 1 USDA classifications of tomato-based on color characteristics

No.	Class	Description
1	Green	Fruit surface completely green, varying from light to dark green
2	Breaker	Pink, red, or tannish yellow color on not more than 10%
3	Pink	30% to 60% pinkish or red
4	Turning	10% to 30% fruit surface is red, pink, or tannish Yellow
5	Light Red	60% to 90% surface shows pinkish-red or red
6	Red	Over 90% red; desirable table ripeness

Note: All percentages speak of both color distribution and intensity

2.3 Nutritional composition of tomato

The nutritional composition of tomato was described as below: Water content of tomato is quite high and is about 92-95%. The solid matter content of tomatoes ranges from 5.5-9.5% of which about 1% is seed and skin (on a fresh weight basis). Antioxidants that are present in tomatoes are vitamin C (160-240mg/kg), pro-vitamin A carotenes (6-9mg/kg), lycopene (30-200mg/kg), phenolic compounds like flavonoids (5-50mg/kg) and phenolic acids (10-50mg/kg). In this way, tomatoes are a valuable source of ascorbic acid that helps to protect our bodies from various diseases. Generally, red tomato's average nutritional value per 100 grams is a follows are listed below the table.

Table 2 Nutritional value of raw tomatoes

Nutrients	Quantity
Energy	74 KJ (18 kcal)
Fat	1.2 g
Fiber	0.2 g
Protein	13.96 g
Vitamins	
Vitamin A	42 µg
β – carotene	449 µg
Vitamin C	14 mg
Vitamin E	0.54 mg
Lycopene	2573 µg

Source: USDA Nutrient Database (https://fdc.nal.usda.gov/index.html)

2.4 Physicochemical characteristics of tomato

The Physical attributes of the raw tomatoes (size, weight, pericarp, wall thickness, color) and dried tomatoes quality (pH and color) were determined. The chemical constituents are concerned with the quality of tomato fruit in respect to color, texture, flavor, nutritive value, and wholesomeness. In general, high sugar contents, redness of color, and firm texture are associated with the prominence of rich flavor. Biochemical changes as influenced by the growth, maturation, and environment of tomato fruit(Shende et al., 2012).

The quality and flavor of the processed products depend on chemical components like reducing sugar, acidity, ascorbic acid, lycopene, ß-carotene, total soluble solid, and total sugar which has been reported to vary greatly with variety. The desirable qualities for a tomato cultivar to be used for processing include high total soluble solids (4-8°Brix), acidity not less than 0.4%, pH less than 4.5, uniform red color, smooth surface, free from wrinkles, small core, firm flesh and uniform ripening (Shende et al., 2012).

2.5 Drying technology

Drying, in general, usually means the removal of water from the material. The drying time, temperature, and water activity influence the final product quality. Low temperatures generally have a positive influence on the quality, but require longer processing times. The drying of foods is used as a preservation technique. The microorganisms that cause food spoilage and decay cannot grow and multiply in the absence of water. When the water content is reduced below about 12wt %, the microorganisms are not active.

Table 3 Moisture standard of dried tomatoes

Moisture designation	Min. percentage	Max. percentage	Texture
High moisture	25	50	Soft and pliable
Regular moisture	18	25	Firm but pliable
Reduced moisture	12	18	Very firm
Low moisture	5	12	Hard and brittle

Source: UNECE standard DDP-19

2.5.1 The role of drying in the postharvest system

Drying is simply evaporation; putting the material to be dried into an environment that increases the product temperature, decreases the relative humidity of the drying air, and allows drying air circulation. The roles of drying are reduced transportation costs and storage, durable without preservatives and the concentration of nutrients per unit of weight is very high. The agricultural products that are dried traditionally are maize, some fruits (e.g. tomatoes and mangoes), spices (e.g. Chill, garlic, onions), and meat. Direct sun drying or free/natural convection drying over a fire is the traditional practice (Ali et al., 2015).

The safe storage of tomatoes depends in large measure on the moisture content of the product. The importance of moisture content reduction is a decrease in water activity to secure levels which consequently prevent microbiological growth. High water activity is linked to the growth of microorganisms, which leads to a deterioration in the quality of the product and dry matter loss. Most tomato's storage fungi growth is reduced when water activity is lower than 0.88 (Chakraverty et al., 2003).

2.6 Periods of drying

Heat is transferred to evaporate the liquid, and mass is transferred as a vapor or liquid within the solid and as a vapor from the surface. The curve plotted in Figure 2 below represents a typical case when a wet solid loses moisture initially by evaporation from a saturated surface on a solid, followed by a period of evaporation from a saturated surface on a solid and a period of evaporation from a saturated surface of gradually decreasing area and at the end, when the latter evaporated in the interior of the solid. Figure 2a indicates that the drying rate is subject to variation with time or moisture content, further better illustrated by graphically or numerically differentiating the curve and plotting dw/dt verses W, as shown in Figure 2b, or as dw/dt versus t as shown in figure 2c. These rate curves illustrate that the drying process is continuous, not smooth in which only one mechanism controls throughout. Figure 2c has the advantage of showing how long each drying period lasts. Section AB on each curve represents a heating-up period of the solids. Section BC on each curve represents the period of constant rate period. Point C, where the constant rate period ends and the drying rate begin falling, is termed the critical moisture content. The curved portion CD in Figure 2a is termed the falling rate period and, as shown in Figures 2b and 2c, is typified by a continuously changing rate throughout the remainder of the drying cycle. Point E (Figure 2b) represents the point at which all the exposed surface becomes completely unsaturated and mark the beginning of that portion of the drying cycle while the rate of internal moisture movement controls the drying rate of the mechanism of drying. Portion CE in Figure 2b is usually defined as the first falling rate drying period; and portion DE, as the second falling rate period (Chakraverty et al., 2003).

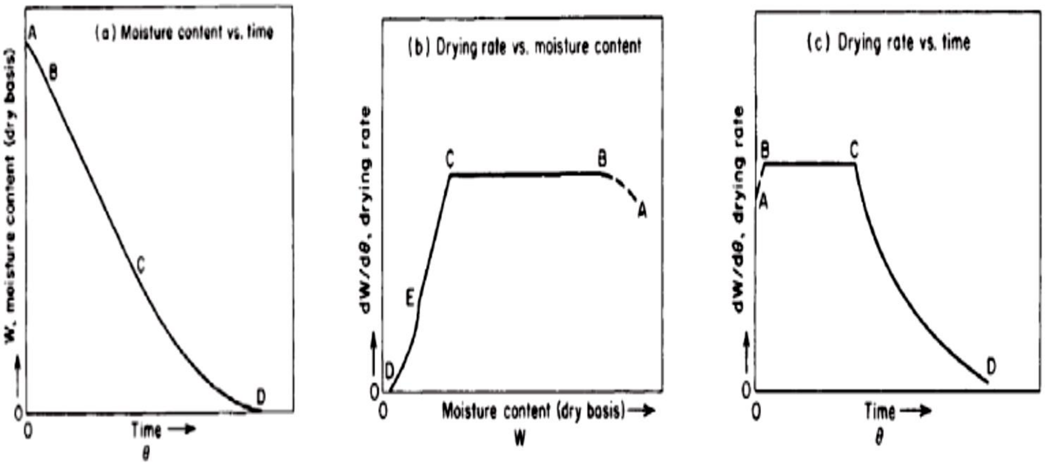


Figure 2 Drying period curves (Chakraverty et al., 2003)

2.6.1 Constant rate period

In the constant rate period, moisture movement within the solid is fast enough to keep a saturated condition on the surface and hence, the rate of drying is controlled by the rate of heat transferred to the evaporating surface. Drying continues by diffusion of vapor from the saturated surface of the material through a stagnant air film into the surrounding and as the rate of mass transfer balances heat transfer, the temperature of the saturated surface remains constant. The magnitude of the constant rate depends upon the following factors: the heat or mass transfer coefficient, the area exposed to the drying medium, the difference in temperature or humidity between the vapor stream and the wet surface of the solid to be dried. All these factors affecting the constant rate period are external variables. The internal mechanism of liquid flow does not affect the constant rate drying period (Chakraverty et al., 2003).

2.6.2 Falling rate period

The falling rate period begins at the level of critical moisture content when the constant rate period ends. This is generally divided into two particular zones: the zone of unsaturated surface drying and the zone where internal moisture movement controls. In the first zone, the whole evaporating surface can no longer be kept and saturated by moisture movement within the solid. The drying rate decreases from the unsaturated part, and hence the rate for the total surface decreases. The drying rate at this stage is governed by the rate of internal moisture movement. Hence, the influence of external variables diminishes. This drying rate period is usually the most dominant in determining the overall drying time to lower moisture content (Hu et al., 2006)

2.7 Drying of tomatoes

The essence of drying in the industries, especially the processing and the food industry cannot be overestimated. To achieve the expected drying of materials, several methods of drying have been developed and further research is still being carried out. Some of these include, but are not restricted to the following listed.

2.7.1 Hot air drying

In hot-air drying, enough water must be removed to lower the water activity to a level that inhibits the growth of microorganisms and reduces the rate at which enzymatic and non-enzymatic reactions occur. Thus, one of the primary requirements in using hot-air drying is to understand the drying process, to be able to predict drying times, establish the distribution of moisture throughout the solid pieces during drying and the influence of the processing variables such as air temperature and velocity, pretreatment and the size of the pieces on drying behavior. Hot-air drying is an alternative drying method. Using hot air dryers leads to a more uniform, hygienic, and attractive product that can be produced rapidly (Gürlek et al., 2009).

2.7.2 Sun drying

Sun-drying is the traditional method of drying in developing countries and it denotes the spreading of foodstuff in the sun (direct sunlight) on a suitable surface such as mat, roof, or drying floors (Al-Shammari et al., 2018). The sun-drying method is cheaply executed, takes a long time, and may be prone to contaminations from microorganisms due to unhygienic exposures (Deák et al., 2015). Moreover, direct exposure to sunlight, or more precisely ultra-violet radiation, can greatly reduce the level of nutrients such as vitamins in the dried product. Since sun-drying depends on uncontrolled factors, production of uniform and standard products is not expected(Copetta et al., 2011).

2.7.3 Solar drying

Solar drying technology seems to be one of the most promising alternatives to reduce post-harvest losses. The solar-dried products have much better color and texture as compared to open sun-dried products. The food is dried using solar thermal energy in a cleaner and healthier way (Anastacia et al., 2011). They can be constructed from locally available materials at a relatively low capital cost and there are no fuel costs. However, dependency on the weather for drying operation is one of the setbacks in solar drying technology (Inyang et al., 2017).

2.7.4 Microwave drying

Microwave drying is an alternative method that has been used in the food industry. Microwaves are electromagnetic waves that range between 0.3 GHz and 300 GHz. The most commonly used frequencies are 915 MHz and 2450 MHz. The microwave heating method dehydrates food by interactions between the electromagnetic energy and polar molecules within the material. Polar molecules rotate in response to the applied oscillating electromagnetic waves. Microwave heating is a desirable alternative drying method since it enhances energy efficiency and has a less negative impact on the quality of the dehydrated products(Sheng et al., 2013).

2.7.5 Oven drying

In conventional oven heating, the heat is transferred from the surface to the interior of the material. This pressure is generated between the surface and interior due to evaporation, such that the interior moisture is driven out and evaporation continues on the surface. However, conventional oven heating has low energy efficiency with negative quality effects (Deng et al., 2019). The oven takes two or three times longer to dry food when compared with other dryers. Thus, the oven is not as efficient and uses more energy. There are two types of ovens namely batch and conveyor ovens. The oven uses a convective process (force air convective and gravity convective). It is used in various industrial applications for drying, curing (rubber), baking, etc. Lapses in oven drying are due to induced evaporation. The explosion can occur since the product when dried reaches its combustion level. It is difficult to get the humidity of the oven due to a lack of flow velocity for easy circulation (Deng et al., 2019).

2.8 Thin layer models of the drying process

Thin-layer drying can be defined as the drying process in which all feed materials to be dried is fully exposed to the drying air under constant drying conditions. Several mathematical models have been developed which are describing the drying process for various agricultural products depending on product type, pretreatment of the product, drying parameters, and drying methods. For these models, only a thin layer drying models is widely used for the designing of the dryers. In the development of thin-layer drying models for agricultural commodities generally, the moisture content of the product at any time after it has been subjected to constant relative humidity and temperature conditions is measured and correlated to the drying parameters. The models used for thin-layer drying are mainly empirical, theoretical, and semi-theoretical types. The most theoretical models widely used are derived from Fick's second law of diffusion. Similarly, some semi-theoretical models are generally derived from Fick's second law and modifications of its simplified forms while others are derived by analogs with Newton's law of cooling (Saravanan et al., 2018).

Table 4 Thin layer drying model equations

No	Model name	Model	Reference
1	Newton	$MR = exp\ (-kt)$	*Lewis (1921)*
2	Page	$MR = exp\ (-kt^n)$	Page (1949)
3	Modified page (I)	$MR = exp\ (-(kt)^n)$	*Overhults, et al.,, (1973*
4	Modified page equation (II)	$MR = exp\ (\frac{t}{d^2})^n$	Diamante and Munro (1993)
5	Henderson and Pabis	$MR = a\ exp\ (-kt)$	*Henderson (1961)*
6	Logarithmic	$MR = a\ exp\ (-kt) + c$	*Ya gcıoglu et al. (1999)*
7	Two-term	$MR = a\ exp\ (-k_1t) + b\ exp(-k_2t)$	*Henderson (1974)*
8	Two term exponential	$MR = a\ exp\ (-kt) + (1 - a)exp(-kat)$	*Sharaf-Eldeen, Blaisdell, and Hamdy, (1980*)
9	Verma et al.	$MR = a\ exp\ (-kt) + (1 - a)exp\ (-gt)$	*Verma et al. (1985)*
10	Midilli et al	$MR = a\ exp(-kt^n) + bt$	*Midilli et al. (2002*

Where: MR= moisture ratio (dimensionless), t = drying time (sec), k = empirical coefficients in the drying models (h^{-1}), a, b, c, and g = model coefficients or empirical constants in the drying models, n = number of terms of the equation or positive integer and d = diameter (m)

2.9 Effects of operating parameters on drying rate

The drying rate of the product is mainly affected by the temperature, relative humidity, and velocity of the surrounding air. To improve the drying rate of high moisture materials with thick layers, skin pretreatments of drying can be considered chemical pretreatments(Deng et al., 2019).

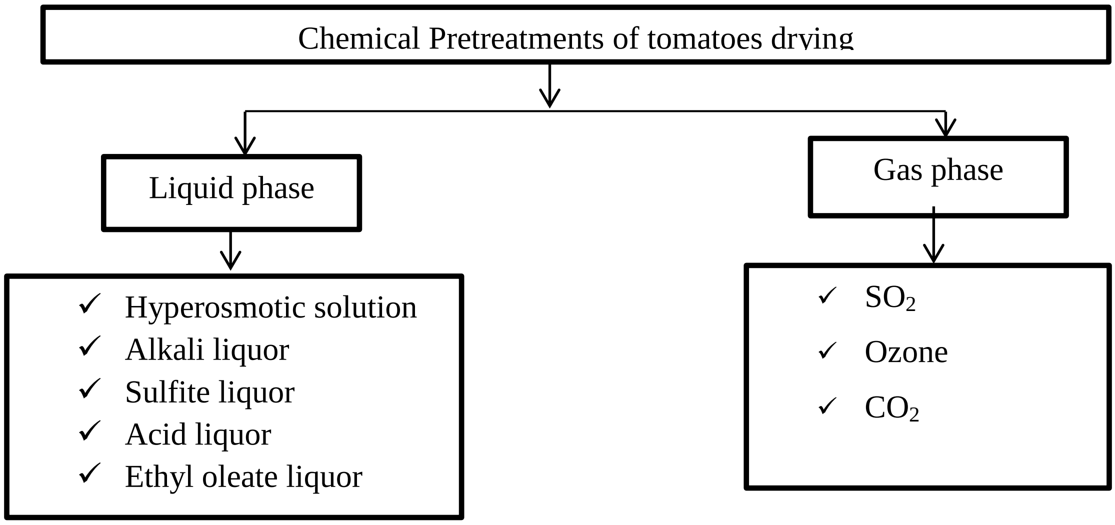


Figure 3 Chemical pretreatment methods of drying

2.9.1 Chemical pretreatments

2.9.1.1Gas phase

Ozone(O_3): places of interest for its high oxidation potential (2.07 MV) applied to inactivate various bacteria, including Gram-negative and Gram-positive and speculated forms, as well as components of the cell envelope, spores, fungal, or viral capsids at relatively low concentrations and short contact times. Ozone may cause an undesirable effect; it may promote oxidative degradation of chemical constituents, causing loss of color, change in aromaticity, and mischaracterization of the initial quality of the food (Freitas-Silva & Venâncio, 2010).

Carbon dioxide(CO_2): pretreatment shows dominant advantages, because of its environment-friendliness and safety for food as well as quality. Its general application form is called the carbonic maceration (CM) technique, invented by Michel Flanzy in 1934, it involves placing the samples into a closed tank with a carbon dioxide-rich atmosphere, this adaptation is reflected almost instantly inside plant materials by the transition from a respiratory to fermentative anaerobic metabolism (Guerrini et al., 2020).

2.9.1.2 Liquid phase

Hyperosmotic solution: is one of the most widely practiced pretreatments before drying to reduce energy consumption and improve food quality. It involves the immersion of material in hypertonic solution (mainly sugar or salt) for several hours. Osmotic dehydration also has adverse effects on the drying rate of some products, attributes to the increased resistance to water flux caused by shrinkage and solutes uptake (Nieto *et al*., 2001).

Sulfite solution: Sulfitation or sulfuring has been widely used in the food industry to reduce darkening during drying and prevent quality loss during the process and storage of foods. It is usually performed using sulfur dioxide gas or water-soluble sulfide salts such as potassium metabisulfite ($K_2S_2O_5$), sodium metabisulfite ($Na_2S_2O_5$), and sodium hydrogen sulfite ($NaHSO_3$). sulfite pretreatment has marked effects on maintaining the color of products, but it also causes a loss of some water-soluble nutritional compounds, creates undesirable flavor and soft texture (Aga et al., 2016)

Acid liquor: Acid pretreatment is also frequently used to improve product quality through inactivating enzymes, enhancing pigment stability, and modifying the texture of agro-products. Citric acid is the most commonly used anti-darkening agent and a texture-modifier of fruits and vegetables. Additionally, ascorbic acid as an antioxidant has been used to pretreat agro-products before drying, as it can reduce the equinoxes to colorless dihydroxy phenols, and form a barrier to oxygen diffusion into the product (Vega-Mercado et al., 2001)

Alkaline liquor: the alkaline dipping pretreatment is primarily used for whole berry fruits, whose outer skin is covered by hydrophobic wax. The wax coating consists largely of oleanolic acid, which leads to a low rate of moisture evaporation during drying, it presents as an obstacle to drying (Urcan et al., 2017). Dipping of berries into alkaline emulsions of ethyl or methyl esters, sodium hydroxide, and potassium carbonate for several minutes can dissolve the wax layer, destroy the microstructure in the epicuticular wax layer (Deng et al., 2019), or even breakdown of intracellular bonding through de-esterification of pectin (Esmaeili et al., 2015). And then enhance the permeability of the skin to moisture, facilitate moisture diffusion and increase the dehydration rate (Deng et al., 2019).

Alkali liquor dipping pretreatment accelerates the drying rate and reduces the drying time, consequently decreasing the deterioration of quality of products, Bingol et al. (2012) showed that alkali dipping pretreatment (potassium carbonate and ethyl oleate solutions at 60℃ for 2 and 3 min), improved the lightness (L- values) of dried grapes by 37%– 55%. The finding was similar to the reports by (Diamante *et al,. 2010*) and (Kipcak & İsmail, 2018) for tomatoes.

The drying process accelerated by the alkali dipping of berries was influenced by the composition of chemical agents, concentration, pH, temperature, and dipping time(I. Doymaz, 2007). The drying time to obtain the same moisture content of tomatoes pretreated with potassium carbonate plus ethyl oleate was shorter than that in potassium carbonate plus olive oil, indicating the organic component of the dipping agent was more influential than potassium carbonate for tomatoes pretreatment. It was consistent with results by (Diamante et al., 2010) and (Ratti & Mujumdar, 1997). However, observed that ethyl oleate solution had a slighter accelerated drying process of plums, while both KOH solution and NaOH solution significantly enhanced weight loss rate. (Aboagye-Nuamah et al., 2018) reported that, the drying rate of tomatoes increased with the temperature of the dipping solution increased, and samples dipped for longer times obtained lower drying time, such as the dipping time at 30 and 40℃ for 3 min reduced the drying time by 11 and 5 h, respectively, compared to 2 min dipping. While alkaline liquor dipping pretreatment also has limitations. Alkali dipping pretreatment may lead leaching, degradation, and oxidation of ascorbic acid, owning to alkaline media, and effects of oxygen caused by micro-crack of the epidermis(Khairi et al., 2015).

Ethyl oleate liquor: is one of the fatty acid ethyl ester (FAEE) formed by the condensation of oleic acid and ethanol. It is colorless to light yellow liquid. Ethyl oleate pre-treatments is prevents loss of color by inactivating enzymes, decrease the drying time by relaxing tissue structure and yield a good quality dried product. Ethyl oleate is used for the Pharmaceutical industry, Transport industry, and Food industry which is used as a food additive and is regulated by the food and drug administration. It is also used as a flavoring agent in food (I. Doymaz, 2007). The drying process accelerated by the alkali dipping of berries was influenced by the composition of chemical agents, concentration, pH, temperature, and dipping time. The drying time to obtain the same moisture content of grapes pretreated with potassium carbonate plus ethyl oleate was shorter than that in potassium carbonate plus olive oil, indicating the organic component of the dipping agent was more influential than potassium carbonate for tomato pretreatment (I. Doymaz, 2007).

To improve the quality and safety of products, the traditional chemical additive pretreatment technique needs to be replaced by a more efficient, safe, and controllable method (i.e. ethyl oleate pretreatment). The effect of temperature, pretreatment with an alkaline emulsion of ethyl oleate (AEEO), and slice thickness on drying and rehydration characteristics of tomato slices was studied. Chemicals like K_2CO_3, Nacl and KCl alkaline are expensive in terms of price as compared with water. However, ethyl oleate can be easily mixing with water to create a high opening tissue. Drying time decreased with increased pretreatment, but it increased considerably with the increased slice thickness of the tomato (Doymaz, 2013)

3. MATERIAL AND METHODS

3.1 Description of the study area

This study was carried out in Bahir Dar University, Ethiopia. It was within the Amhara Regional State located about 578 km northwest of Addis Ababa. Based on Weldegerima *et al.*, (2018) report, the city lies between the latitude of $11^0$35′37″N and longitude of $37^0$23′26″ E. Its average elevation is estimated at 1800 m above sea level. The climate was classified as sub-humid warm temperate with an estimated average annual temperature and rainfall of 19.6^0C and 1,419 mm, respectively (Weldegerima et al., 2018).

3.2 Materials

The basic raw materials are hybrid tomatoes that are Gelila

Table 5 Equipment and chemicals

Chemicals	**Grade**	**Function**
Ethyl oleate	250 g	To decrease drying time
H_2SO_4	78-98% conc.	To determine crude fiber content
H_3BO_3	400 mg	To determine crude protein
NaOH	48-50% conc.	Neutralize acidic media
HPO_3	40- 50 % conc.	For titration to determine vitamin-C
HCl	36% conc.	To prepare standard
Phenolphthalein	98% pure	Indicator
Equipment		
Volumetric flask	SG-500	To handling of chemicals
Colorimeter	Systonic	To measure color characteristics
Spectrophotometer	U-4100	To detected nutrient content
Caliper	Stainless-steel M-105	To measurement dimension
PH meter	PHS-1701	To measure the acidity of the final product
Oven	-	For dying of the sample
Digital balance	model BB30000	Moisture loss recorder
Knife	Inox stainless	Cutting of sample
Polyethylene bags	-	For packaging of dried product

3.3 Methods

The experimental framework of the research

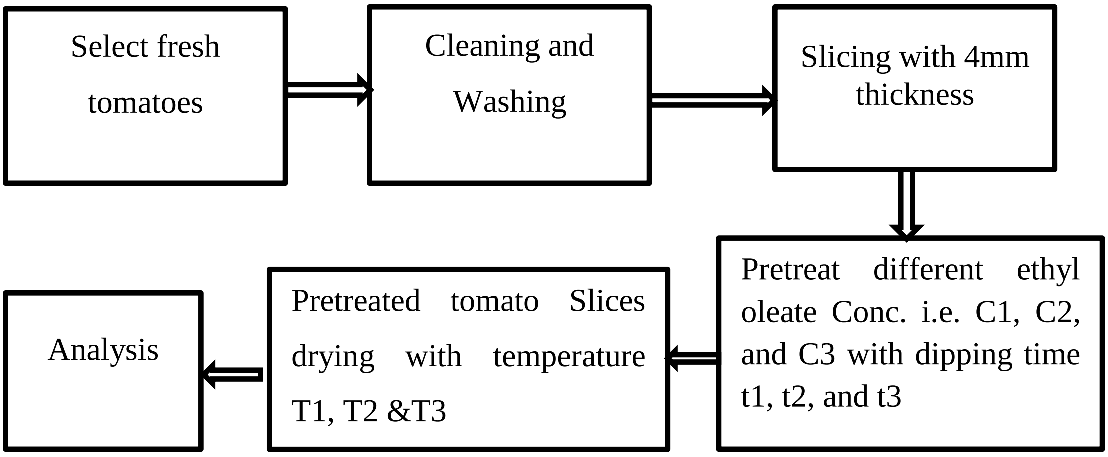


Figure 4 General experimental procedures

Fresh Tomatoes: Firm, red color, and fully ripe tomatoes were collected from the Bahirdar city market and then transported to the laboratory for processing.

Washing: The fresh tomatoes were washed using potable (cold and warm) to remove soil and other unwanted substances from the surfaces.

Sorting: Tomato sorting was done by hand for the removal of defected tomatoes that have a green or green color, bruised, and contaminated.

Cutting: The tomatoes were cut using a clean stainless steel knife. At this stage, coring, and trimming of the unwanted parts affect the quality and appearance of the products. After trimming, tomatoes immerse into different concentrations of ethyl oleate.

3.4 Sample preparation

The experimental process variable should be carried out with design expert software for an experimental design using three-factor Response Surface methodology should be used to study the effect of independent variables which were ethyl oleate concentration, dipping time, and drying temperature on the drying of tomatoes. In sample preparation the following step will be involved:

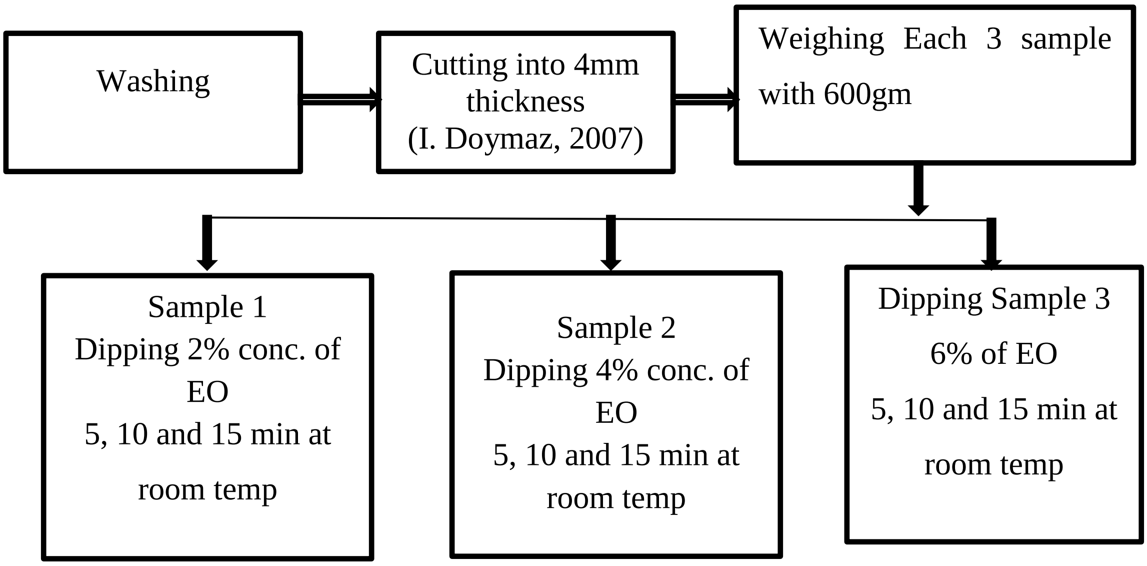


Figure 5 Procedures of sample preparing of drying tomatoes

3.5 Ethyl oleate pretreatment drying process

Oven drying 600 g of tomato slices thickness 4mm (I. Doymaz, 2007) with ethyl dipped ethyl oleate concentration at 2%v/v, 4%v/v, and 6%v/vv (Deshmukh et al., 2013) and (I. Doymaz & Özdemir, 2014) was distributed uniformly as a thin layer onto the stainless steel trays and dried in an oven at 50℃, 60℃, and 70℃ (Kejing et al., 2019).The mass of the samples was measured every 2 hrs during oven drying using a digital balance, measuring to an accuracy of 0.001 g (Arslan & Özcan, 2011). A tray with the sample was taken out of the drying chamber, weigh on the digital balance, and place back into the chamber. The drying was carried out to the final moisture content of about 92-96 % (w.b) removal. After drying, all products are packed in polyethylene bags wrapped in aluminium foil to prevent light damage and stored at ambient temperature.

3.6 Mathematical modeling of drying curve

The moisture ratio (MR) of the sample was calculated using the following equation:

$$M_R = \frac{M_t - M_e}{M_o - M_e} \quad 1$$

Where M_t is the moisture content at any time (kg water/kg dry solid), M_o is the initial moisture content (kg water/kg dry solid), and M_e is the equilibrium moisture content of the sample (kg water/kg dry solid) Hence, equation 1 is simplified in equation1.1(Karabacak et al., 2018).

$M_R = \frac{M_t}{M_o}$ 2

Drying curves are obtained for the tomatoes are wither fitted or not with different models.

Table 6 Drying models used in modeling of freshly harvested Tomatoes

No	Model name	Model	Reference
1	Newton	$MR = exp(-kt)$	Lewis (1921)
2	Page	$MR = exp(-kt^n)$	Page (1949)
3	Modified page (I)	$MR = exp(-(kt)^n)$	Overhults *et al., 1973*
4	Modified page equation (II)	$MR = exp\left(\frac{t}{d^2}\right)^n$	Diamante *et al., 1993*
5	Henderson and Pabis	$MR = a\ exp(-kt)$	Henderson (1961)
6	Logarithmic	$MR = a\ exp(-kt) + c$	Ya gcıoglu *et al. 1999*
7	Two-term	$MR = a\ exp(-k_1t) + b\ exp(-k_2t)$	Henderson (1974)
8	Two-term exponential	$MR = a\ exp(-kt) + (1 - a)exp(-kat)$	Sharaf-Eldeen *et al., 1980*
9	Verma et al.	$MR = a\ exp(-kt) + (1 - a)exp(-gt)$	Verma *et al. 1985*
10	Midilli et al	$MR = a\ exp(-ktn) + bt$	Midilli *et al. 2002*

Where: MR= moisture ratio (dimensionless), t = drying time (sec), k = empirical coefficients in the drying models (h^{-1}), a, b, c, and g = model coefficients or empirical constants in the drying models, n = number of terms of the equation or positive integer, D = diffusion coefficient ($m^2\ s^{-1}$), and d = diameter (m)

Among the 10 well-known drying models of freshly harvested tomatoes which are given in (Table 6) the best will be selected, using three parameters: higher values for the coefficient of determination (χ^2) and least values of RMSE and SSE (near to zero) (Tunde-Akintunde&Ogunlakin,2011).

$$SSE = \left(\frac{1}{N}\right) \sum_{i=1}^{N} [MR_{Pedi} - MR_{expi}]^2 \quad (3)$$

$$\text{RMSE} = \left(\frac{1}{N}\right) \sum_{i=1}^{N} [MR_{Pedi-}MR_{expi}{}^{2}]^{\frac{1}{2}} \tag{4}$$

$$\chi^2 = \frac{\left[\sum_{i=1}^{N} (MR_{exp,i} - \overline{MR_{exp}})(MR_{exp} - \overline{MR_{pre}})\right]^2}{(\sum_{i=1}^{N} (MR_{exp} - \overline{MR_{exp}})^2) - (\sum_{i=1}^{N} (MR_{exp} - \overline{MR_{exp}})^2)} \tag{5}$$

Where: $MR_{exp,i}$ =experimental moisture ratio of ith data; $MR_{pre,i}$=predicted moisture ratio of ith data; $\overline{MR_{exp}}$ = Mean moisture ratio and N=number of observations.

3.7 Determination of effective moisture diffusivity

It has been accepted that the drying characteristics of organic products in the falling rate period can be described by using Fick's diffusion equation. Although the diffusivity equation is not the best equation to fit experimental data, it provides an approximate method to present a common quantitative comparison between different products in the aspect of moisture transfer because it can describe the average diffusion coefficient in the entire drying process. The solution to this equation developed by Crank can be used for several regular-shaped bodies such as rectangular, cylindrical, and spherical products. For a long drying period, this solution can be written in a logarithmic form as follows(Workneh & Oke, 2013):

$$MR = \frac{M - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \exp\left(\frac{-\pi^2 D_{eff} t}{4L_0^2}\right) \tag{6}$$

Where: Deff is the effective moisture diffusivity (m^2/s), t is the drying time (s) and L_0 is the half-thickness of the samples (m). Eq. (6), therefore, can be written as follows:

$$lN(MR) = \frac{-\pi^2 D_{eff}}{4L_0^2} t + ln\frac{8}{\pi^2} \tag{7}$$

The experimental drying data were plotted in terms of Ln (MR) against time at different temperatures. The slope derived from the linear regression of the graphs was used to calculate the effective moisture diffusivity. The slope obtained is

$$slope = \frac{-\pi^2 D_{eff}}{4L_0^2} \tag{8}$$

3.8 Determination of activation energy

The dependence of the effective diffusivity on the different drying temperatures can be predicted appropriately using the Arrhenius equation which is given by equation 9 (Workneh & Oke, 2013).

$$D_{eff} = D_0(\frac{E_a}{R(T+273.15)}) \quad (9)$$

Where: D_{eff} is the effective moisture diffusivity in m^2/s, D_o is the pre-exponential factor of Arrhenius equation or maximum diffusion coefficient (at infinite temperature) in m^2/s, E_a is the activation energy in kJ/mole, R is the universal gas constant in kJ/mole K and T is the temperature in °C.

Linearizing the equation gives

$$D_{eff} = \left(-\frac{1}{R(\mathrm{T}+273.15)}\right) E_a + lnD_0 \quad (10)$$

The activation E_a was obtained by plotting lnD_{eff} against $\left(-\frac{1}{R(T+273.15)}\right)$.

3.9 Data analysis

Optimization of process variable should be carried out with design expert software for an experimental design using three-factor Response Surface methodology should be used to study the effect of independent variables which were ethyl oleate concentrated, dipping time and temperature on the drying of tomatoes.

3.10 Raw tomatoes and dried tomatoes proximate analyses

The proximate, mineral composition and physiochemical analysis were conducted at Bahirdar University institute technology organic chemistry, food chemistry, and post-harvest laboratory; those are moisture content, crude fat, crude protein, crude fiber, PH, total soluble solid (TSS), total acidity (TA), color and ash.

3. 10.1 Determination of moisture content

The empty dish was dried and lid in the oven at 103°C for 3hr and transferred to desiccators to cool. The empty dish was weighed and lid. About 15g of sample was weighed to the dish and the dish with the sample was placed in the oven; then dry for 3hr at 103°C. After drying, the dish with a partially covered lid was transferred to the desiccators to cool. The dish and its dried sample were reweighed (Official methods of Analysis, 2000).

$$\text{Moisture (\%)} = \frac{\mathrm{W}_2 - \mathrm{W}_3}{\mathrm{W}_2 - \mathrm{W}_1} * 100 \quad (11)$$

Where; W_1 = weight (g) of empty dish, W_2 = weight (g) of wet sample before drying +empty dish and W_3 = weight (g) of sample after drying +empty dish

3. 10.2 drying rate

The drying rate of the tomatoes sample varies with the final moisture content and drying temperature. The drying rate was measured using the following Equation(İ. Doymaz, 2010).

$$DR = \frac{M_i - M_f}{DT} \quad (12)$$

Where, DR=drying rate, percentage of moisture content per hour, M_i=weight of initial mass content, M_f = weight of final mass content of Tomato on the dry basis, and DT = Drying time (hr).

3. 10.3 Determination of ash content

To determine the ash content of the tomato, the crucible and cover were placed in the oven at 550℃ overnight to ensure that the impurities on the surface crucible were burned. Then the crucible was cooled in the desiccators for 30min. The crucible and lid were weighed (g) to 3 decimal places. 6 g of the sample was weighed into the crucible and heated over the Bunsen flame with the lid half covered. When fumes are no longer produced place crucible and lid in the furnace. Heat at 550℃ overnight until the white-gray color was achieved and do not cover with a lid during ash in the furnace. The lid was placed after complete heating to prevent loss of fluffy ash and cool down in the desiccators. The ash with the crucible and lid was weighed when the sample turned to gray (Ketema Balcha Debela1*, Derbew Belew2, 2016).

$$\text{Total Ash}(\%) = \frac{M_3 - M_1}{M_2 - M_1} * 100 \quad (13)$$

Where: M_1 = mass (g) of the empty crucible with lid, M_2 = mass (g) of sample plus crucible before ash with lid, and M_3 = mass (g) of sample plus crucible after ashing with lid.

3. 10.4 Determination of crude protein content

Protein content was analyzed by Kjeldahl method destruction of the starch sample by Sulphuric acid. Nitrogen was liberated as ammonia, distilled, collected, and titrated. 0.5 g of sample, 1g of catalyst mixture (K_2SO_4 mixed with anhydrous $CuSO_4$ in the ratio of 10:1), and 6 ml of conc. Sulphuric acid was added into a 500 ml digestion flask. Then the flask was placed on the heater to bring the temperature to 350^0c and digested for 2 hours to react. As soon as the violent reaction was ceased, the heat was increased and the destruction was continued until the content appeared light green. It was then cooled and diluted with distilled water followed by 25ml (40% NaOH). The digested and diluted solution was transferred into the sample compartment of the distiller lined into the receiver flask that contains 25ml of 4% boric acid solution. It was then distilled until a total volume of 150 ml was collected (NH_3 as distillate). Finally, the excess standard acid in the distillate was titrated with a standard (0.1N HCl). The volume of HCl consumed was recorded from the burette reading after the steel blue color occurred. The protein content was determined as a mean of three measurements (Official methods of Analysis, 2000).

$$\text{Nitrogen(N)\%} = \left(\frac{V_{HCl}\text{in L} * N_{HCl} * (\text{ca. } 0.1) * 14}{\text{sample weight on a dry basis}} * 100\right) * 100 \quad (14)$$

Where V is the volume of HCl in L consumed to the end point of the titration, N is the normality of HCl used often is about 0.1N and 14 is the molecular weight of nitrogen. To convert % of nitrogen to % of protein by using appropriate conversion factors as follows: % protein = 6.25*% N

3. 10.5 Determination of crude fat content

The extraction cylinders were washed in hot water, removed all impurities, and placed in an oven for about 1 hour at 105ºC. Take out it, put them into a desiccator, and weighed it (W1). Place it back into a desiccator. The bottom of an extraction thimble was covered with a layer of fat-free cotton.2g of the sample was weighed accurately in the thimble (W) and covered with a layer of fat-free cotton. The thimble was put in the extraction chamber. The extraction cylinder was taken out from the desiccators, put on the bracket, check the number and 50 ml of petroleum ether was added into the extraction cylinder and move into the heating plank. Let the extraction go on for at least 4 hours. The extraction cylinder was disconnected and put in the drying oven at 70℃ for at least 30 min. put it in the desiccators to cool for at least half an hour. The extraction cylinder was weighed immediately after being taken out of the desiccators (W2) (Rybak-Chmielewska, 2003).

$$\text{Crude fat(\%)} = \frac{W_2 - W_1}{W_0} * 100 \qquad (15)$$

Where; W_1 = weight of the extraction cylinder (g), W_2 = weight of the extraction cylinder plus the dried crude fat (g) and W_0 = weight of sample (g)

3. 10.6 Determination of vitamin-C

Vitamin-C is determined by the titration method as described by (Mozumder, Rahman, Kamal, 2012). For this, 10 ml of sample is taken in a volumetric flask and made up to volume 100 ml with 3% Meta phosphoric acid and filter. Pipette 10 ml of filtrates into a conical flask and titrate with the standard dye solution to the pink end point.

3. 10.7 Determination of crude fiber content

The moisture and fat-free sample (5 g) are poured into a cleaned and kiln-dried 500 ml beaker containing 200 ml of preheated H_2SO_4 (0.255N). The mixture is boiling for 30 minutes keeping the volume constant by the addition of distilled water at frequent intervals. The mixture is then filtered through a muslin cloth and the residue is washed several times with hot water until it is making acid-free. After boiling the mixture is filtered through a muslin cloth and the residue is washed several times with hot water followed by washing with alcohol and then enters until the sample is making alkali free. This alkali-free sample is then dried in an oven at 105℃ for four hours, cooled in a desiccator, and weighed (a). Next, this crucible is heated in a muffle furnace at 600℃ for 3-4 hours, cool, and weighs again (b). This difference in the weights (a-b) represents the weight of crude fiber present in the sample(*AOAC 2000. Pdf*).

3. 10.8 PH values

The pH values of the samples were measured directly through a pH meter (PHS-series). Five grams (5g) of each sample was first dissolved in 50 cm^3 distilled water in a beaker and thoroughly shaken. The pH meter was standardized using buffer solutions pH 4 and 7 and the values were taken(Srivalli et al., 2016).

3. 10.9 Total acidity

A total of 10 ml of tomato juice Filtered sample was put into a 100 ml measuring flask. The sample was added 2 drops of Phenolphthalein and titrated with 0.1 N NaOH until pink (Rybak-Chmielewska, 2003). The calculation of the total acid is done by the formula:

$$\text{Total acidity}(\%) = \frac{a}{b} * 100 \tag{16}$$

Where; a= amount of NaOH 0.1 N for titration (ml), and b = 10 ml of material.

3. 10.10 Total soluble solids

Total Soluble solids of tomato juice were determined using a digital Refractometer at ambient temperature and results were reported as °Brix (Rybak-Chmielewska, 2003).

3. 10.11 Color characteristics

Color is one of the most important quality parameters of tomato fruit that affects customer purchase decisions. The main color quality of tomatoes is redness and it is affected by lycopene content(Khairi et al., 2015). Color measurements were performed on the surface of the tomato three points in the bottom and equatorial region by the colorimeter. The color measurement *L** describes lightness (*L**=0 for black, *L**=100 for white), *a** describes intensity in red-green (*a**>0 for red, *a**<0 for green), *b** describes intensity in blue-yellow (*b**>0 for yellow, *b**<0 for blue).

Equations for further analysis to describe color qualities were shown below the equation (Sacilik et al., 2019).

$$\text{Redness compared to yellowness}(\%) = \frac{\text{a}}{\text{b}} * 100 \tag{17}$$

4. RESULT AND DISCUSSION

4.1 Physical and chemical characterization freshly harvested tomatoes

The data on physicochemical properties of agro-food materials are valuable because they are needed as input to models, predicting the quality and product behavior. The correlation between laboratory test processes and the physicochemical qualities of tomato varieties will contribute to developing an optimal solution for processing and product quality(Demissew et al., 2017). The physical and chemical properties of tomatoes used for this study are listed in Table 7.

Table 7 Mean ± SD of physicochemical properties of freshly harvested tomatoes

Physicochemical analysis	Current study	Other findings	Reference
Moisture content (%)	93.25±0.034	93.3 %	(John Famurewa, 2019)
Ash content (%)	49.22±0.16	49.34	(JAV Famurewa & Raji, 2011)
Fat content (%)	1.82±0.02	1.75	(JAV Famurewa & Raji, 2011)
Protein content(%)	12.7±0.01	13.96	(Surendar et al., 2018)
Vitamin-C (mg/100g)	13.93±0.25	14	(Silva et al., 2013)
Fiber content (%)	0.27±0.2	0.2	(JAV Famurewa & Raji, 2011)
Ph	4.31±0.03	4.5	(Demissew et al., 2017)
TSS (^{0}brix)	4.2±0.22	4.6	(Demissew et al., 2017)
Titratable acidity (%)	31.5±2.55	34	(Kk et al., 2017)
Color (%)	69.55±12.49	Above 60	(Sacilik et al., 2019)

N.B: the experimental images are listed in appendix C

The result obtained under this study is a good agreement with the literature result even if a few variations. There are several reasons behind this varied range of solids percentage in tomato composition, like variety, rainfall, soil characteristics, and irrigation (Nasir et al., 2015).

4.2 Experimental drying curve

The relationship between moisture content and drying time of tomato slices to oven drying is given in Figure 6 to 8. The moisture content decreases continuously with drying time. As can be seen from the data presented, the time required to dry tomato slice to 6.75% moisture content decreased with an increase in ethyl oleate concentration from 2 to 6 %v/v combined with dipping time 5 min to 15 min, at 50°C, 60℃, and 70℃ respectively. The instantaneous moisture content rapidly decreases as the ethyl oleate concentration increases which is due to faster moisture diffusion from the center of the tomato slices to the surface. Heating from surface to center conduction stage is largely eliminated due to gradual vapor pressure differences. During conventional drying, moisture is initially evaporated from the surface while in the internal tomato slices water diffuses to the surface slowly. Under pretreatment of oven drying, internal heat generation leads to an increase in internal temperature and vapor pressure, both of which help liquid flow towards the surface, thus increasing the drying rate. More of the applied energy is converted to heat within the tomato slice. The time was reduced from 19 to 8 hr, 13 to 4 hr, 9 to 2 hr at 50℃, 60℃, and 70℃ respectively. During drying of tomato slices using 4%v/v ethyl oleate concentration and 10 min dipping time it improves 57.89%, 69.23%, and 77.78% at 50°C, 60℃, and 70℃ respectively. In general, the time required to reduce the dimensionless moisture content to any given level was highly dependent on the drying conditions, being the highest at 70°C and the lowest at 50°C drying temperature. Internal heating using oven drying was found to be an effective method for drying enhancement which is in agreement with previous reports (I. Doymaz & Özdemir, 2014) and (Kumar et al., 2016). Heat is generated when microwave interacts with the polar water molecules in fruit and vegetables and a significantly high drying rate was achieved when compared with oven drying alone(I. Doymaz & Özdemir, 2014).

Generally, from Figure 6 to 8 it is observed that drying occurred faster in 70 ℃ the oven dryer than 50℃ and 60℃ with dipping time at 10 min and ethyl oleate concentration at 4% v/v. This is demonstrated by the consistent lowering of moisture content of the tomatoes in the oven dryer, a similar observation was reported in (Onifade et al., 2013) and (Purkayastha et al., 2013).

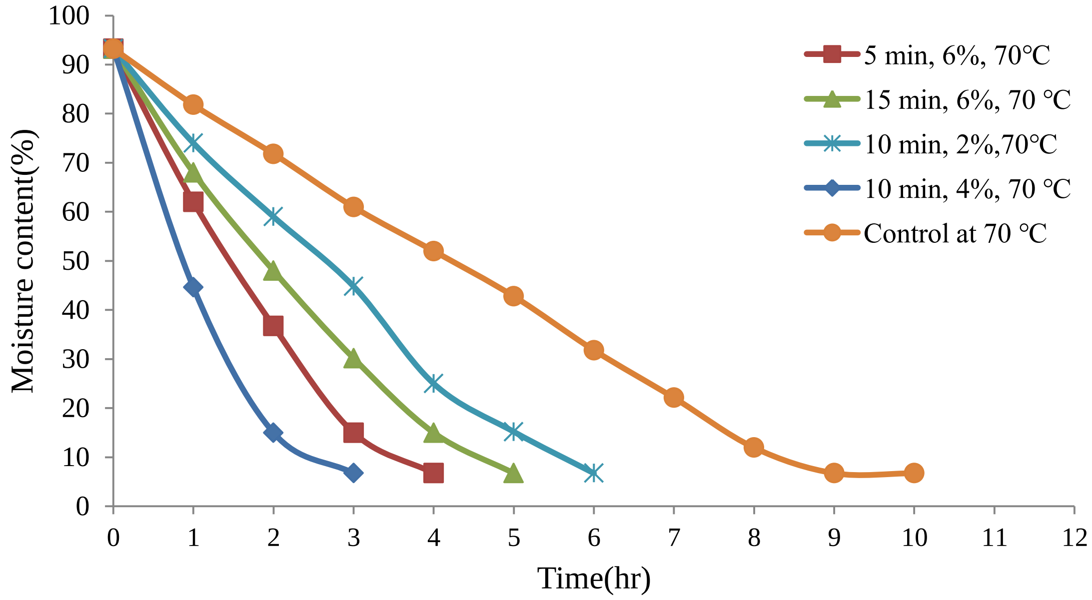


Figure 6 Variation of moisture content with drying time at 70 °C

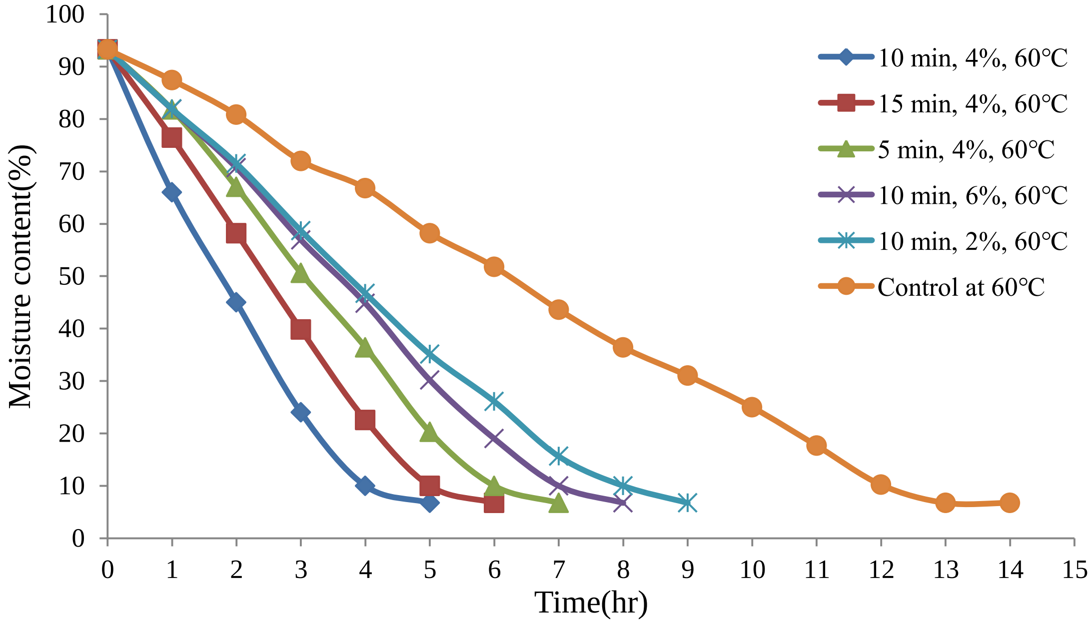


Figure 7 Variation of moisture content with drying time at 60 °C

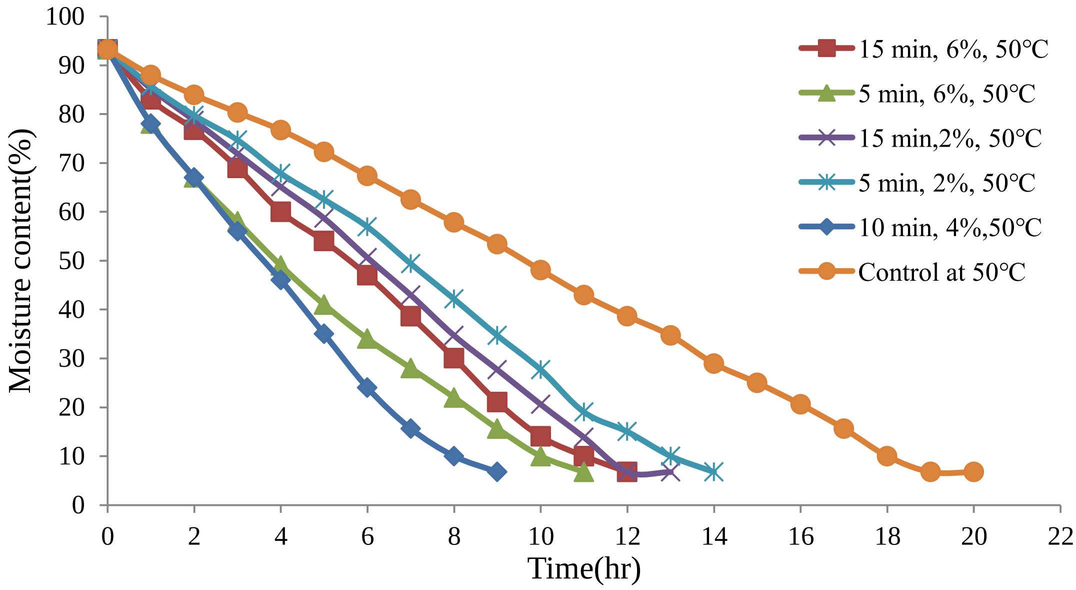


Figure 8 Variation of moisture ratio with drying time at 50°C

4.3 Effects of drying temperature on physicochemical properties

The analysis of the results indicated that there was a temperature effect of drying in all parameters during the drying study. From the above figure 6 to 8 at 10 min dipping time and 4 %v/v ethyl oleate concentration with 50, 60, and 70°C had high drying rate. Since tomatoes are used for food, the amount of nutrients in it after drying at 10 min dipping time and 4 %v/v ethyl oleate concentration was measured (Table 8).

Table 8 Mean ± SD of physicochemical properties of dried tomatoes at high drying rate

Physicochemical analysis	The experimental result at 4% and 10 min		
	50°C	60°C	70°C
Ash content (%)	42 ± 0.012	48.06±0.02	51.02 ±0.03
Crude fat content (gm)	1.78±0.016	1.64±0.05	1.46 ±0.016
Protein content (%)	9.623±0.167	11.187±0.36	12.18±0.059
Vitamin-C(mg/100gm)	9.042±0.032	13.04±0.36	7.68±0.21
crude fiber content (gm)	0.264±0.059	0.218±0.055	0.198±0.08
PH	4.43±0.0499	4.31±0.265	4.20±0.13
TSS (^{0}brix)	4.48±0.107	4.07 ±0.115	3.86±0.18
Titratable acidity	28.81±0.796	31.91±0.485	32.4±1.08
Color (%)	69.81±0.89	66.248±0.488	64.05±0.88

Ash is the inorganic residue remaining after the water and organic matter has been removed by way of heating of a given meal. The maximum ash content material (dry base) was found as 51.02 % in samples dried at 70°C which is higher than control and different treatment combinations (Table 7 and 8). The result confirmed that the ash content material was once raised at high temperatures of drying. This could be as a result of the removal of moisture which tends to increase the concentration of nutrients (Yusufe et al., 2017a). There used to be increasing in ash content material observed, it can be viewed from the result, there used to be more ash in the dried tomato sample than in the control (fresh) tomato; this implies that there are greater combustible substances in dried tomato than in control (fresh) because of denaturing of the samples at higher temperatures.

Crude Fat (gm) content between dried and control (fresh) tomato samples influenced utilizing results of drying temperature. The result confirmed that as the drying temperature increased the fats content material decreased. This ought to be attributed to the oxidation of fat at a greater temperature than at a lower temperature. On the other hand, the lowering of fats in dried tomatoes might also have a contribution in decreasing the rancidity of the product during storage and cholesterol level in the diet. Results from this study are comparable to the finding of (Yusufe et al., 2017b) who said that the fats content material (8.1%) of clean tomato samples was once higher than (1.3 %) oven-dried samples at 90°C.

Crude protein (%) content is affected by the drying temperature. The protein content material at 50°C used to be lower than the samples dried at 70°C (12.18%). The result indicated that increasing the protein content with accelerated drying temperature. This study is comparable to the finding of (Yusufe et al., 2017b) who reported that the crude protein content (9.1%) of clean tomato samples used to be higher than (13.95%) oven-dried samples at 90°C.

The crude fiber (gm) was significantly affected by drying temperature. The result revealed that the maximum 0.264 gm at 50°C and the minimum crude fiber content of 0.198 gm were found in samples dried at 70°C. The crude fiber contents of dried tomato decreased as temperature increased. This was a result of the high-temperature drying process that can disrupt the cellular matrix of the products(Yusufe et al., 2017b).

The vitamin-C contents are affected by drying temperature. The sample dried at 70 was estimably affected recording an average value of 7.68% of vitamin C compared to the value recorded in the dried sample 50℃ (9.04%). The lower value of vitamin C or the damage of vitamin during drying was primarily due to heat (high temperatures and long duration of drying) and might be oxidation and light (Yusufe et al., 2017b). Similar findings were reported by (Yusufe et al., 2017b) who reported that Vitamin C progressively decreased as the processing temperature increased and suggested that it does not require excessive heat treatment.

pH price amongst dried samples due to the pretreatment effects and temperature of drying. The highest (4.53) and lowest (4.20) were reported in sample dried at 50℃ and 70℃ respectively. The result revealed that the pH of tomato reduced as temperature increased; this can also be associated with the extent of titratable acidity. According to (Físico-química & Tomate, 2014), pH under 4.5 is a high-quality attribute, due to the fact it arrests the improvement of microorganisms in the completed product all through industrial processing. Similar findings had been reported via (Yusufe et al., 2017b) who reported that pH values reduced as the processing temperature increased.

TSS content is determining the suitability of tomato varieties for processing. From total soluble solid content, 50 to 65% are sugars (glucose and fructose), and their quantity and ratios influence the organoleptic quality of tomatoes(Yusufe et al., 2017b). The leftover soluble solids are mainly citric and malic acids, lipids, and other constituents in lower proportions. The TSS contents of tomatoes were increased after drying; it was affected by the temperature of drying. The maximum value (4.48^0brix) was recorded in samples dried at 50℃ and the minimum value (3.86) was recorded at 70℃. The result is also in conformity with (Yusufe et al., 2017b) who indicated that the value of TSS contents of tomato was reduced at higher temperatures; this could be due to high drying temperature, which may degrade the sugars.

Citric acid is the most important acid present in tomatoes and it is a significant decisive factor in consumer acceptance of processed products since the high value is associated with a satisfactory acidic flavor. Titratable acidity (TA) was affected by pretreatment and the drying temperature. The highest value (32.41L) was found in samples dried at 70℃ while the lowest value (28.81L) was at 50℃. The results indicated that titratable acidity was increased with temperatures of drying. During the drying process, a rise in acidity is chiefly attributed to the high amount of moisture lost from the samples and decreasing of pH. These values were in agreement with the outcomes reported by (Yusufe et al., 2017a) observed an increase in titratable acidity of sample oven-dried.

The color of the dried sample was affected by drying temperature. The colors of sliced tomatoes were 69.81%, 66.248%, and 64.05% at 50℃, 60℃, and 70 ℃ respectively. The color was highest than the samples dried at 50℃ (69.81%). The result indicated that a decrease of color was more in samples dried at high temperatures. This shows the high temperature involved in drying of sliced tomatoes denaturing of the sample that gives darker. In accordance with (Workneh & Oke, 2013), stated that as drying temperature increased from 60℃ to 80℃, they observed the color of dried tomato decreased from 46.02 to 39.09 %.

4.3 Thin-layer drying kinetics

The moisture ratio (MR) data, which was obtained by the thin-layer drying experiment, was essential to describe different thin-layer drying models. To authenticate the goodness of fit of each model the moisture ratio was calculated from the moisture content data obtained from the thin layer drying experiment of tomato in oven drying. Then, curve fitting was carried on for different drying models by using non-linear regression analysis. In this experiment, curve fitting computations of MR with the drying time were carried on for ten different thin-layer drying models.

The results of the statistical analysis undertaken with those models are presented in appendix B. Based on statistical results obtained by curve fitting, the Modified page (I) drying model showed good agreement with the experimental data and gave the best result for the tomatoes drying the sample. From the results, higher values of χ^2 and lower values of RMSE and SSE were obtained by the Modified page (I) drying model. However, these models could be considered to represent the thin layer drying behavior of freshly harvested tomatoes in the oven dryer. Modified page (I) model was derived from Modified page of general series solutions to the analytical solution to the diffusion equation of Fick’s second law. It predicts the moisture transport well and its parameters represent the physical properties of the drying process. Modified page (I) drying model was selected by other researchers to predict the drying characteristics of the tomatoes hot-air dryer (Journal et al., 2014), for drying of

Convective drying of cape gooseberry fruits (Journal et al., 2014), Effect of Ethyl oleate pretreatment on drying of Ginger in oven drying (Sacilik et al., 2019) and drying of tomato in solar tunnel dryer (Sacilik et al., 2019). From the appendix B the constants and coefficients of the accepted model for the oven drying of tomatoes were as below:

$MR = \exp(-(kt)^n)$

Equation , which is known as the modified Page (I) model, also has two parameters (K and n), and note that $k = K^n$. It can be said that both models, without any calculation, should have identical fits with the same parameter n, χ^2, RMSE and SSE values, since n determines the shape (Buzrul, 2022). The correlation between the parameters of the modified Page model k= 0.084 was low at 50℃ with compared at 70℃ which is k= 0.166. this shows that when the tdrying temperature increase the error (k) will reduce to improve the modified Page model but it certainly has no effect on the model's fit.

50℃

k=0.084, n=5.371………………..………………………………………… 4%, 10 min

60℃

k=0.125, n=4.166 ……………………………………………………………. 4%, 10 min

70℃

k=0.166, n=3.483 ……………………………………………………………. 4%, 10 min

Figure 9 shows the variations of experimental and predicted MRs by the Modified page (I) drying model with drying time. It was observed that the selected model gave good conformity between experimental and predicted MRs. This reveals the fitness of the selected model in describing the drying characteristics of freshly harvested tomatoes in the oven dryer with ethyl oleate pretreatment. The fitness of the model was also validated with the R^2 = 0.9999 band of the experimental and predicted values. Hence, the validation of the Modified page (I) model was confirmed by comparing the predicted moisture contents to the observed values as indicated in Figure 9. The Modified page (I) model provided satisfactorily good conformity between predicted and experimental moisture ratios, and the predicted data were lined around the straight line, which showed the suitability of this model in describing the oven drying behavior of tomatoes.

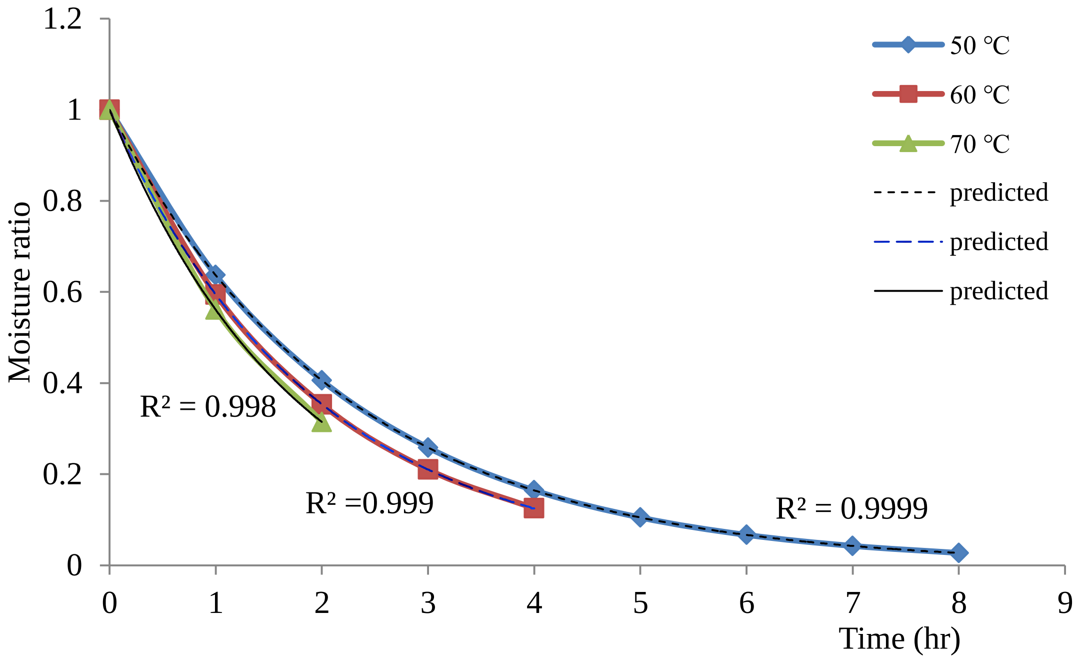


Figure 9 Variation of moisture ratio with drying time in the oven drying experimental and predicted data (using Modified page (I) drying model)

4.4 Effective moisture diffusivity

The effective moisture diffusivity (D_{eff}) of a food material characterizes its intrinsic moisture mass transport property. Effective moisture diffusivity could describe all possible mechanisms of moisture movement within the foods, such as liquid diffusion, vapour diffusion, surface diffusion, capillary flow and hydrodynamic flow (Kejing et al., 2019). The method of slopes as shown in equation (8) was used to calculate the effective moisture diffusivity coefficient. Slopes of graphs of Ln(MR) versus time for the experimental drying were determined (Workneh & Oke, 2013). The values of the effective diffusivity coefficients of the tomato samples varied with $5.0575*10^{-10}$ ‚ $6.14269*10^{-10}$, and $7.3766*10^{-10}$ m^2/s. It can be seen that the values of D_{eff} increased greatly with increasing temperature. Drying at 70℃ gave the highest D_{eff} values. D_{eff} values for tomatoes are similar to those estimated by different authors for tomatoes and other vegetables: 5.65 to 7.53 * 10^{-10} m^2/s for ethyl oleate solution pretreated tomatoes dried from 55℃to 70℃(I. Doymaz, 2007) and 1.68 * 10^{-9} to 4.77 * 10^{-9} m^2/s for tomatoes dried by using hot air ventilation 50℃ to 70℃ (Workneh & Oke, 2013). The values of D_{eff} obtained ($1.7366*10^{-8}$ to $2.82198*10^{-8}$ m^2/s); indicate moisture diffusivity in tomatoes is affected by the drying temperature. This is possibly due to the fact that the water spread was once in the main due to the mass transport mechanism throughout drying. The moisture from the inner core of the product migrates and replaces the surface and capillary moisture as they evaporated and eventual diffusion of moisture grew to become the predominant mechanism. The drying temperature has a great effect on the inside mass switch all through drying since the greater the drying temperature, the greater the rate at which diffusion of moisture from the inside regions to the surface occurs. This is because surface water elimination is quicker at excessive temperature considering the fact that most of the drying mechanism is vapor diffusion and the viscosity of the dipping solution plays a major part in the process. The solutions which are less viscous concentration of ethyl oleate are observed to have high drying temperature and also partial breakdown of waxy layer present on the plum samples, thus resulting in an increase in mass transfer across the membrane (i.e. increase in permeability). This is similar to that thin layer modeling of microwave-convective drying of Tomato Slices (Workneh & Oke, 2013).

4.5 Activation energy

The activation energy can be interpreted as the minimum energy that should be provided to break water-water interactions or water-solid and to cross the water molecules from one point to some other in the solid. The smaller Ea value of the sample indicates that water molecules can more quite simply cross in the sample. D_{eff} increased following the increase of temperature, viscosity of ethyl oleate solution decreases, and drying time will also decreases because of the extraction of moisture easly grown from interior to outer surface of tomatoes. The activation energies (Ea) of dried tomatoes have been calculated with the help of the Arrhenius equation. The effective diffusivities were obtained from Fick's second law were plotted against the reciprocal of the absolute temperatures for the calculation of the activation energies. The activation energy values were found to be 18.06, 22.28, and 28.94 kJ/mol, pretreated at 70°C, 60°C, and 50°C respectively. Pre-treated tomatoes clearly showed slightly lower activation energy at high temperatures. It is higher than the activation energies of tomatoes drying (27.09 kJ/mol) (Workneh & Oke, 2013), and lower than the activation energy of tomatoes drying with pretreatments of ethyl oleate (17.40 kJ/mol) and the higher activation energy was 32.94 kJ/mol (İ. Doymaz, 2010). This can be attributed to a partial breakdown of waxy layer present on the plum samples, thus resulting in an increase in mass transfer across the membrane (i.e. increase in permeability).

4.6 Analysis of experimental results

Ethyl oleate pretreatment of tomato drying response drying rate slice was affected by different treating parameters including drying temperature, the concentration of ethyl oleate, and socking or dipping time.

Table 9 Designed experiments according to response surface face center design and measured

Run	Factors			Response 1
	Time (min)	Concentration (v/v %)	Temperature (℃)	Drying rate (gm/hr)
1	5	2	70	118
2	10	4	60	143.3
3	15	2	70	132.58
4	15	6	70	178.86
5	10	4	60	143.32
6	10	4	70	228
7	10	4	60	143.28
8	15	2	50	55.74
9	5	2	50	36.25
10	10	6	60	112
11	10	4	60	143.22
12	15	6	50	39
13	10	4	60	142
14	10	4	60	141.98
15	10	4	50	116.62
16	15	4	60	116
17	10	2	60	88.64
18	5	6	50	37.98
19	5	4	60	107.13
20	5	6	70	182.36

The experimental design selected for this study was the response surface method (RSM) and the response measured was the drying rate. RSM provides an estimate for the value of responses for every possible combination of the factors by varying the values of all factors in parallel, making it possible to comprehend a multidimensional surface with nonlinear shapes (Jerry Fireman et. al., 2011). In this section, the results obtained from the pretreatment of tomatoes in ethyl oleate solution are presented in table 10.

4.6.1 Analysis of variance (ANOVA)

Table 9 Model summary statistics

Source	Std.Dev	R^2	Adjusted R^2	Predicted R^2	PRESS	
Linear	31.32	0.673	0.6117	0.4363	27046.81	
2FI	32.27	0.7179	0.5876	-0.3916	66775.07	
Quadratic	0.57	0.9999	0.9999	0.9998	10.05	Suggested
Cubic	0.66	0.9999	0.9998	0.9909	435.95	Aliased

From table 10 the quadratic model is suggested among the other models. This is due to the highest value of the "Adjusted R^2" and the "Predicted R^2" and also the model is not aliased.

4.6.2 ANOVA for response surface quadratic model

To determine whether or not the quadratic model is significantly affected by the Parameters listed in the design, it was crucial to perform an analysis of variance (ANOVA). The Probability values (P-values) were used to perform as a device to check the significance of each coefficient, which also showed the interaction strength of each parameter. The smaller the p-values are, the bigger the significance of the corresponding coefficient.

The Model F-value of 16277.73 implies the model is significant.There is only a 0.01% chance that a "Model F-value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case, A, B, C, AB, AC, BC, A^2, B^2, C^2 are significant model terms.Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Table 10 Analysis of variance (ANOVA) on response drying rate

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	Judgment
Model	47981.45	9	5331.27	16277.73	< 0.0001	significant
A-time	163.7	1	163.7	499.82	< 0.0001	significant
B-conc	1415.86	1	1415.86	4322.99	< 0.0001	significant
C-temp	30714.87	1	30714.87	93780.33	< 0.0001	significant
AB	166.99	1	166.99	509.86	< 0.0001	significant
AC	11.12	1	11.12	33.94	0.0002	significant
BC	1973.49	1	1973.49	6025.57	< 0.0001	significant
A^2	2748.09	1	2748.09	8390.63	< 0.0001	significant
B^2	5050.94	1	5050.94	15421.82	< 0.0001	significant
C^2	2334.04	1	2334.04	7126.42	< 0.0001	significant
Residual	3.28	10	0.33			
Lack of Fit	1.05	5	0.21	0.47	0.7851	Not significant
Pure Error	2.22	5	0.44			
Cor Total	47984.73	19				

The "Lack of Fit F-value" of 0.47 implies the Lack of Fit is not significant relative to the pure error. There is a 78.51% chance that a "Lack of Fit F-value" this large could occur due to noise. Lack of fit is bad because we want the model to fit. This relatively low probability (<10%) is troubling. This shows the temperature, ethyl oleate concentration, dipping time, the interaction between drying temperature and ethyl oleate concentration, interaction between drying temperature and dipping time, ethyl oleate concentration, and dipping time affects the drying rate significantly.

Table 11 Model adequacy measure

Std. Dev.	0.57	R-Squared	0.9999
Mean	120.31	Adj R-Squared	0.9999
C.V. %	0.48	Pred R-Squared	0.9998
PRESS	10.05	Adeq Precision	472.72

The R^2 value is equal to 0.9999 it indicates that the regression line perfectly fits the data and these results imply that the predicted values were found to be in good agreement with experimental values (R-Squared = 0.9999 and Adj-R-Squared= 0.9999), indicating the achievement of the Response surface model. The model's goodness of fit was checked by regression coefficient (R^2). The Predicted R^2 of 0.9999 is in reasonable agreement with the Adjusted R^2 of 0.9999; furthermore, the difference is less than 0.2. The adequacy precision measures the signal-to-noise ratio. A ratio greater than 4 is desirable. In this model, the ratio of 472.720 indicates an adequate signal. This model can be used to navigate the design space.

Development of regression model equation

A model equation is a mathematical expression in which the whole model was expressed in a single equation that helps to maximize response. The model equation that correlates the response (dying rate) to the process variables in terms of actual value after excluding the insignificant terms was given below. The predicted model for the ethanol yield in terms of the coded factors is given in (equation 12).

Final Equation in Terms of Coded Factors:

$$\text{drying rate} = +142.98 + 4.05*A + 11.90*B + 55.42*C - 4.57*A*B - 1.18*A*C + 15.71*B*C - 31.61*A^2 - 42.86*B^2 + 29.13*C^2 \quad \text{……………………………(12)}$$

The equation developed from the regression model terms of coded factors represented the percentage of drying rate. The yield was as response and affected by linear terms such as dipping time (A), ethyl oleate concentration (B) and drying temperature (C), and pure quadratics terms (A^2, B^2, and C^2) and interaction quadratic terms (AB, AC, and BC). Based on the coefficients in (equation 12), it was clear that the drying rate increases with the increase of dipping time (A), ethyl oleate concentration (B), and dying temperature (C). Dipping time, ethyl oleate concentration, and drying temperature have a positive linear effect on drying rate. Interaction of dipping time and drying temperature (BC) has also a possetive quadratic effect on the response while the interaction of dipping time and ethyl oleate concentration (AB) and also the interaction of ethyl oleate concentration and temperature (AC) has a negative effect on drying rate.

4.6.3 Normal probability plot

The normal probability plot, (Fig 10), indicates the residuals followed by the normal % probability distribution, in the case of this experimental data the points in the plots are in a good fit to the straight line; this shows that the quadratic polynomial model satisfies the analysis of the assumptions of variance (ANOVA) i.e. the effects of ethyl oleate pretreatment, dipping time and drying temperature are affected rhe drying rate.

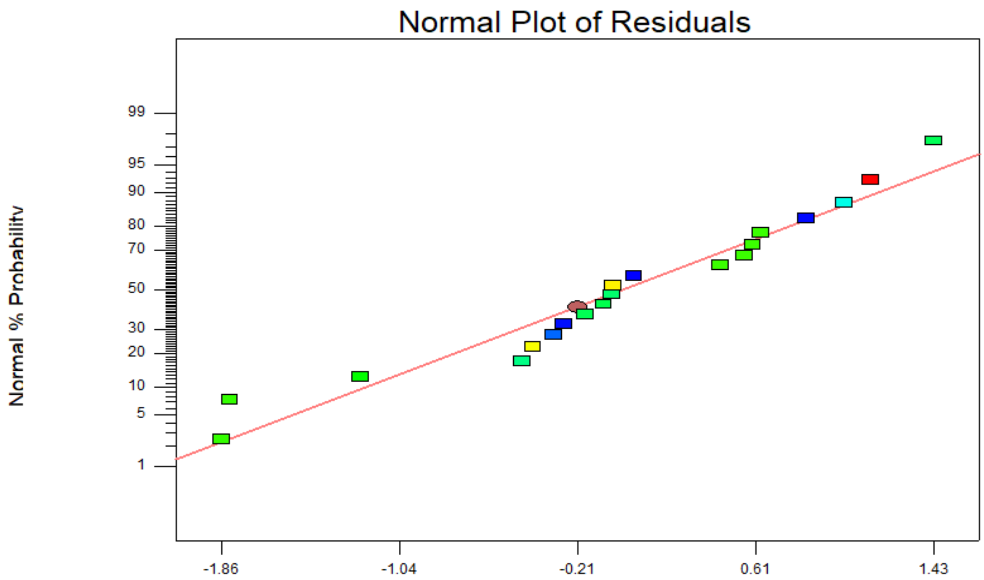


Figure 10 Normal probability plot of residuals versus Studentized residuals values of drying rate

4.6.4 Interaction effects of process variables on drying rate

The drying of tomatoes can be affected by many factors but due to time and computational cost it is tedious to deal with all, so in this case, after conducting a preliminary experiment the main parameters (dipping time, concentration, and temperature) are selected. The three-dimensional response surfaces effect was plotted in figures (11-13) as a function of the interactions of any two of the variables by holding the other value of the variable at the center point.

4.6.4.1. Interaction effect of dipping time and ethyl oleate concentration

In the interaction of dipping time and ethyl oleate concentration as shown in (Figure 11), a high drying rate is obtained nearly (a little higher time) at the center point and then the drying rate decreases at any direction in the model. This is because tissue cuticular opens up and after some time contrast. From fig 11 it is seen that the maximum drying rate of 228gm /hr was obtained at dipping time 10 min, ethyl oleate concentration 4, and drying temperature 70°C.

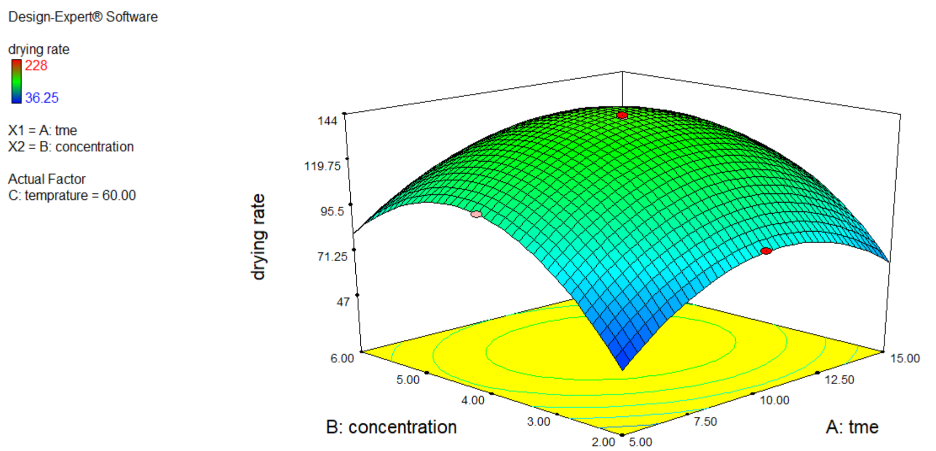


Figure 11 Response surface plots of the interaction effects of dipping time and ethyl oleate concentration on the drying rat

4.6.4.2. Interaction effect of dipping time and drying temperature

From the interaction plot of dipping time and drying temperature (Figure 12), it is observed that the drying rate increase with an increase of both dipping time and drying temperature up to the center point while further increasing both parameters results in the reduction of drying rate(Correia et al., 2015). The maximum drying rate of 228 gm/hr was obtained at dipping time 10 min, ethyl oleate concentration 4, and drying temperature 70°C.

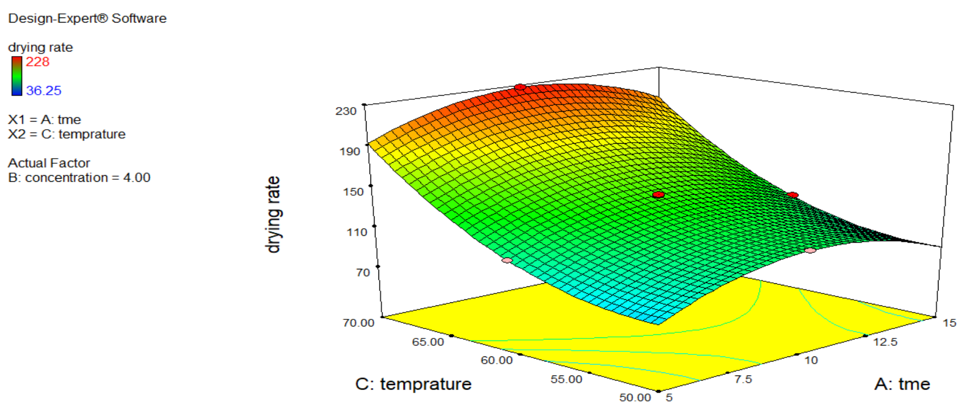


Figure 12 Response surface plots of the interaction effect of dipping time and drying temperature on drying rate at a constant concentration.

4.6.4.3. Interaction effect of ethyl oleate concentration and drying temperature

From the interaction plot of ethyl oleate concentration and drying temperature (Figure 13), both ethyl oleate concentration and drying temperature shows an increment in drying rate up to the center point and further increasing results reduction of drying rate. The maximum drying rate of 228 gm/hr is obtained at dipping time 10 min, ethyl oleate concentration 4, and drying temperature 70°C. This observation agreed with the findings of when the temperature increases drying rate of tomatoes also increases drying rate(Correia et al., 2015).

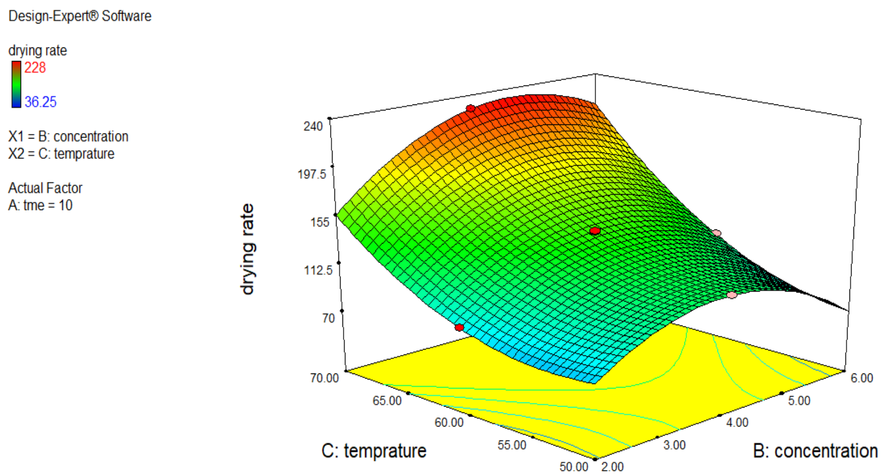


Figure 13 Response surface plots of the interaction effect of ethyl oleate and temperature on drying rate at constant dipping time

4.6.5 Optimization of drying parameters using response surface methodology

Response surface methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving, and optimizing processes. It also has important applications in the design, development, and formulation of new products, as well as in the improvement of existing product designs. The optimization of drying conditions for pretreatment of ethyl oleate pretreatment was summarized in table 13.

Table 12 Constraints for optimization of drying rate

Name	Goal	Lower Limit	Upper Limit
Time	Is in range	5	15
Concentration	Is in range	2	6
Temperature	Is in range	50	70

The desirability lies between 0 and 1 and it represents the closeness of a response to its ideal value. If a response falls within the unacceptable intervals, the desirability is 0, and if a response falls within the ideal intervals or the response reaches its ideal value, the desirability is 1. So in this case the desirability values of 1indicates the closeness of the response to the ideal value.

Table 13 Optimized drying rate on the effects of ethyl oleate pretreatment

Number	time	Conc.	temp	drying rate	Desirability	
1	10.19	4.14	69.92	228.452	1	Selected

4.6.6 Model validation

Using the optimized condition obtained from the Response surface methodology (i.e. table 14), an experiment was conducted. According to (Hu et al., 2006) study, the drying rate was 9.33gm/hr using ethyl oleate with alkaline solution (Nacl and KCl) and 70 °C hot air drying for 20 min. The experimental result showed that the drying rate of the current study using ethyl oleate with water solution was 228±0.021gm/hr and the model predicted value was 228.452gm/hr. So, it is possible to say that this is in good agreement with the predicted one. Therefore, the model is considered to be accurate and reliable for predicting the drying rate. This observation agreed with the findings of when the ethyl oleate was used to pretreat drying of tomatoes it increase the drying rate and saved energy cost (I. Doymaz, 2007) and (Deng et al., 2019). Since tomatoes are used for food, the amount of nutrients in it after drying was measured. From table 15 the optimization of model validation had maximum nutrient content. The result obtained under this study table 16 is a good agreement with fresh tomatoes results even if a few variations.

Table 14 Analysis of physicochemical properties at the optimized condition

10.19 min, 4.14%v/v, 69.92 °C		
Physicochemical analysis	Dried tomatoes	Raw tomatoes
Crude fiber	0.256±0.01	0.27±0.2
Vitamin-C	12.64±0.01	13.93±0.25
Protein	12.62±0.01	12.7±0.01
crude fat	1.72±0.055	1.78±0.02
PH	4.56±0.02	4.31±0.03
TSS	4.26±0.015	4.2±0.22
TA	29.91±0.07	31.5±2.55
Color	66.97±9.74	69.55±12.49

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study showed that the oven dryer is capable of drying tomatoes under ethyl oleate pretreatment. All drying processes of tomatoes drying in the oven occurred in the falling rate period. Tomatoes drying in an oven with ethyl oleate pretreatment took the hourly moisture removal rate of 228gm/hr. Response Surface Methodology (RSM) experiments were used to optimize the drying conditions such as ethyl oleate concentration (2-6%v/v), dipping time (5-15 min), and drying temperature (50-70℃). From the analysis of variance, it was observed that all parameters have a significant effect on drying rate. The optimum drying rate of 228.452 gm/hr was obtained at a dipping time of 10.19 min, ethyl oleate concentration 4.14%v/v, and drying temperature 69.92℃. The experimental result obtained under these optimum conditions results in a drying rate of 228gm /hr. Since the experimental result is under the model predicted value; it shows the reliability of the predicted quadratic model. From mathematical drying models, the Modified page (I) drying model could adequately describe the oven drying behavior of tomatoes in a newly ethyl oleate pretreatment because of R^2 = 0.9999. It is expected that tomatoes drying in an oven dryer with ethyl oleate pretreatment will help reduce the drying time and obtain more quality dried products and to reduce postharvest loss of tomatoes.

5.2 Recommendations

Based on the results of this study, the following aspects are considered as possible areas for future research. This study was focused on the drying effects of ethyl oleate pretreatment on oven drying of Gelila tomatoes. The oven operates at a constant inlet airflow rate of 2m/s. the drying air flow rate affects the drying process. So, it is recommended that the effect of air flow rate on the drying performance of tomatoes should be studied.

The drying process depended on the dryer types. Thus, the effect of ethyl oleate on other drying methods for tomatoes drying should be studied.

The drying characteristics of other agricultural products (like potato, carrot, mango…) in the oven dryer should be tested. The carotenoid content of tomatoes that dried in an oven dryer can be one area of research for the future.

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APPENDIXES

Appendix A: percent moistures and drying rate

Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
73.1	1	44.59644323
40.5	2	6.75
40.5	3	6.75

5 min, 6%, 70℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
148.9	1	72.80053727
65	2	37.69230769
40.5	3	6.75
40.5	4	6.75

5 min, 2%, 70℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
222.5	1	81.79775281
126.6	2	68.00947867
82.3	3	50.78979344
61.4	4	34.03908795
50.5	5	19.8019802
40.5	6	6.75
40.5	7	6.75

15 min, 2%,70℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
184.1	1	78.00108637
107.7	2	62.39554318
71.3	3	43.19775596
51.8	4	21.81467181
40.5	5	6.75
40.5	6	6.75

Control at 70 ℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
222.5	1	81.79775281
143.6	2	71.79665738
103.8	3	60.98265896
84.4	4	52.01421801
70.8	5	42.79661017
59.4	6	31.81818182
52	7	22.11538462
46	8	11.95652174
40.5	9	6.75
40.5	10	6.75

10 min, 4%, 60℃		
Mass(gm)	Time(hr)	Moisture(%)
600	0	93.25
144.6	1	71.99170124
78.9	2	48.66920152
53.3	3	24.01500938
40.5	4	6.75
40.5	5	6.75

15 min, 4%, 60℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
171.6	1	76.3986014
96.9	2	58.20433437
67.3	3	39.82169391
52.3	4	22.56214149
40.5	5	6.75
40.5	6	6.75

5 min, 4%, 60℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
222.5	1	81.79775281
122.7	2	66.99266504
82	3	50.6097561
63.7	4	36.42072214
50.8	5	20.27559055

40.5	6	6.75
40.5	7	6.75

10 min, 6%, 60℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
223	1	81.83856502
138	2	70.65217391
94	3	56.91489362
73.4	4	44.82288828
58	5	30.17241379
50	6	19
40.5	7	6.75
40.5	8	6.75

10 min, 2%, 60℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
224	1	81.91964286
142	2	71.47887324
98	3	58.67346939
76	4	46.71052632
62.4	5	35.09615385
54.8	6	26.09489051
48	7	15.625
40.5	8	6.75
40.5	9	6.75

Control at 60℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
321.4	1	87.3988799
210.9	2	80.79658606
144.6	3	71.99170124
122	4	66.80327869
96.9	5	58.20433437
84	6	51.78571429
71.8	7	43.59331476
63.7	8	36.42072214
58.7	9	31.00511073
54	10	25
49.2	11	17.68292683

45.1	12	10.19955654
40.5	13	6.75
40.5	14	6.75

10 min, 4%,50°C		
Mass(gm)	Time(hr)	Moisture(%)
600	0	93.25
268	1	84.8880597
160	2	74.6875
104	3	61.05769231
81	4	50
67	5	39.55223881
56	6	27.67857143
48	7	15.625
40.5	8	6.75
40.5	9	6.75

15 min, 6%, 50°C		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
269	1	84.94423792
184.1	2	78.00108637
138.7	3	70.80028839
105	4	61.42857143
90.4	5	55.19911504
76.4	6	46.9895288
66	7	38.63636364
57.9	8	30.05181347
51.3	9	21.05263158
47.1	10	14.01273885
40.5	11	6.75
40.5	12	6.75

5 min, 6%, 50°C		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
269	1	84.94423792
182	2	77.74725275
130	3	68.84615385
98	4	58.67346939
82	5	50.6097561
68	6	40.44117647

60	7	32.5
54	8	25
48	9	15.625
40.5	10	6.75
40.5	11	6.75

15 min,2%, 50℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
274	1	85.2189781
190	2	78.68421053
144	3	71.875
116	4	65.0862069
98	5	58.67346939
82	6	50.6097561
71	7	42.95774648
62	8	34.67741935
56	9	27.67857143
51	10	20.58823529
47	11	13.82978723
40.5	12	6.75
40.5	13	6.75

5 min, 2%, 50℃		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
284	1	85.73943662
200	2	79.75
160	3	74.6875
126	4	67.85714286
108	5	62.5
94	6	56.91489362
80	7	49.375
70	8	42.14285714
62	9	34.67741935
56	10	27.67857143
50	11	19
46	12	11.95652174
40.5	13	6.75
40.5	14	6.75

Control at 50°C		
Mass(gm)	Time(hr)	Moisture (%)
600	0	93.25
338	1	88.01775148
252	2	83.92857143
206	3	80.33980583
174	4	76.72413793
146	5	72.26027397
124	6	67.33870968
108	7	62.5
96	8	57.8125
86.8	9	53.34101382
78	10	48.07692308
71	11	42.95774648
66	12	38.63636364
62	13	34.67741935
57	14	28.94736842
54	15	25
51	16	20.58823529
48	17	15.625
45	18	10
40.5	19	6.75
40.5	20	6.75

Appendix B: statistical analysis for the drying of tomatoes with different ethyl oleate con., dipping time, and drying temperature fitted with drying models

❖ **At 50°C**

		6%,5 min			
Model name	Model	constants	χ^2	RMSE	SSE
Newton	MR = exp(-kt)	k=0.055	0.66	0.2168	0.4231
Page	MR = exp($-kt^n$)	k=3.47E-6,n=4.788	0.989	0.0439	0.01349
Modified page (I)	MR = exp($-(kt)^n$)	k=0.072, n=4.788	0.9892	0.0439	0.01349
Modified page equation(II)	MR = exp $((t/d^2)^n$	d=34.8, n=-66.874	0.66	0.53901	0.32428
Henderson and Pabis	MR = a exp(-kt)	k=0.07, a=1.188	0.722	0.20807	0.34633
Logarithmic	MR = a exp(-kt) + c	k=8E-5,a=706.5,c=-705.28	0.858	0.09053	0.05737
Two-term	MR = a exp($-k_1t$) +b exp($-k_2t$)	k1=0.07,a=0.593,b=0.594, k2=0.07	0.722	0.21475	0.27671
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.00012, a=424.2	0.66	0.08061	0.05199
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.055, a=0.081, g=0.055	0.66	0.16556	0.19188
Midilli et al	MR = a exp(-ktn) + bt	k=-40, a=1.28,b=-0.065, n=-124.7	0.889	0.16627	0.13823
		6%,15 min			
Newton	MR = exp(-kt)	k=0.06	0.72	0.19406	0.33894
Page	MR = exp($-kt^n$)	k=7.58E-5,n=3.653	0.99	0.04059	0.01153
Modified page (I)	MR = exp($-(kt)^n$)	k=0.075, n=3.653	0.99	0.04059	0.01153
Modified page (II)	MR = exp $((t/d^2)^n$	d=88.36, n=-471.3	0.72	0.55578	0.47109
Henderson and Pabis	MR = a exp(-kt)	k=0.076, a=1.182	0.778	0.18327	0.2687

Logarithmic	MR = a exp(-kt) + c	k=9.158E-5,a=630.6 ,c=-629.5	0.909	0.0732	0.03751
Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.091,a=1.38,b= -0.38, k2=4.4E5	0.834	0.18293	0.20077
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.131, a=2.38	0.902	0.06832	0.03734
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=-0.42, a=9.63, g=-0.049	0.97	0.25281	0.44739
Midilli et al	MR = a exp(-ktn) + bt	k=4.9E-5, a=0.984,b=-0.002, n=3.776	0.992	0.25845	0.33399
		4%,10 min			
Newton	MR = exp(-kt)	k=0.065	0.653	0.22917	0.42014
Page	MR = exp(-kt^n)	k=1.623E-6,n=5.371	0.991	0.04278	0.01098
Modified page (I)	MR = exp(-$(kt)^n$)	k=0.084, n=5.371	0.9913	0.04278	0.01098
Modified page (II)	MR = exp ($(t/d^2)^n$	d=28.681, n=-53.187	0.653	0.56609	0.20653
Henderson and Pabis	MR = a exp(-kt)	k=0.082, a=1.187	0.71	0.22367	0.35021
Logarithmic	MR = a exp(-kt) + c	k=8.15E-5 ,a=802.2,c=-801.2	0.85	0.24215	0.35182
Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.101,a=1.416,b=-0.416, k2=3.5E3	0.773	0.23424	0.27434
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.144, a=2.428	0.847	0.10299	0.07424
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.065, a=0.855, g=0.065	0.653	0.21383	0.27434
Midilli et al	MR = a exp(-ktn) + bt	k=2.34E-7, a=0.96,b=0.002, n=6.177	0.995	0.30674	0.37635
		4%,15 min			
Newton	MR = exp(-kt)	k=0.058	0.684	0.21052	0.39886

Page	MR = exp(-kt^n)	k=1.73E-5,n=4.209	0.991	0.03496	0.00856
Modified page (I)	MR = exp(-$(kt)^n$)	k=0.074, n=4.209	0.9901	0.03496	0.00856
Modified page equation(II)	MR = exp $((t/d^2)^n$	d=2.347, n=-0.319	0.684	0.2717	0.59055
Henderson and Pabis	MR = a exp(-kt)	k=0.073, a=1.192	0.747	0.19992	0.31975
Logarithmic	MR = a exp(-kt) + c	k=7.96E-5,a=729.69, c=-728.5	0.883	0.0871	0.05311
Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.089,a=1.394,b=-0.394, k2=4.74E5	0.805	0.20234	0.24566
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.129, a=2.419	0.882	0.08001	0.05121
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.189, a=118.1, g=0.192	0.896	0.18733	0.24566
Midilli et al	MR = a exp(-ktn) + bt	k=9.12E6, a=0.98,b= 0.001, n=4.457	0.994	0.14799	0.10951
		2%,5 min			
Newton	MR = exp(-kt)	k=0.061	0.672	0.22398	0.45151
Page	MR = exp(-kt^n)	k=4.26E-6,n=4.813	0.989	0.03298	0.00761
Modified page (I)	MR = exp(-$(kt)^n$)	k=0.077, n=4.813	0.990	0.03298	0.00761
Modified page equation(II)	MR = exp $((t/d^2)^n$	d=72.7, n=-321.145	0.672	0.24506	0.48045
Henderson and Pabis	MR = a exp(-kt)	k=0.077, a=1.202	0.735	0.21351	0.36471
Logarithmic	MR = a exp(-kt) + c	k=8.233E-5,a=733.8 ,c=-732.6	0.874	0.33075	0.76577
Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.094,a=1.422,b=-0.422, k2=5.214E5	0.796	0.22181	0.29521
Two-term exponential	MR = a exp(-kt) +(1	k=0.134, a=2.445	0.872	0.23929	0.45808

	- a)exp(-kat)				
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.198, a=124, g=0.2	0.887	0.16418	0.18868
Midilli et al	MR = a exp(-ktn) + bt	k=1.13E-6, a=0.971,b=0.003, n=5.37	0.997	0.37733	0.71188

❖ **At 60℃**

6%,10 min					
Model name	Model	constants	χ^2	RMSE	SSE
Newton	MR = exp(-kt)	k=0.075	0.67	0.22307	0.34831
Page	MR = $exp(-kt^n)$	k=8E-6,n=4.979	0.979	0.06693	0.0224
Modified page (I)	MR = $exp(-(kt)^n)$	k=0.095, n=4.979	0.979	0.06693	0.0224
Modified page (II)	MR = $exp ((t/d^2)^n$	d=207.5, n=-3.25E3	0.67	0.24961	0.37382
Henderson and Pabis	MR = a exp(-kt)	k=0.093, a=1.169	0.719	0.22223	0.2963
Logarithmic	MR = a exp(-kt) + c	k=8.45E-5,a=866,c=-865.178	0.855	0.27118	0.36769
Two-term	MR = a $exp(-k_1t)$ +b $exp(-k_2t)$	k1=0.118,a=1.423,b=-0.423, k2=5.52E6	0.784	0.23833	0.2272
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.164, a=2.4	0.849	0.10244	0.06296
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.241, a=126.78, g=0.244	0.863	0.31582	0.49872
Midilli et al	MR = a exp(-ktn) + bt	k=0.049, a=1.315,b=-0.087, n=-0.946	0.891	0.41367	0.51337
4%,15 min					
Newton	MR = exp(-kt)	k=0.085	0.713	0.21196	0.31449
Page	MR = $exp(-kt^n)$	k=5.34E-5,n=4.282	0.99	0.04676	0.01093

Modified page (I)	MR = exp(-(kt)^n)	k=0.101, n=4.282	0.991	0.04676	0.01093
Modified page (II)	MR = exp ((t/d^2)^n	d=242.98, n=-4.99E3	0.713	0.61179	0.22457
Henderson and Pabis	MR = a exp(-kt)	k=0.103, a=1.172	0.761	0.2091	0.26234
Logarithmic	MR = a exp(-kt) + c	k=0.000125,a=639.2, c=-638	0.895	0.21057	0.22169
Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.131,a=1.457,b= -0.457, k2=151.4	0.83	0.2161	0.18679
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.178, a=2.408	0.887	0.10646	0.068
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.131, a=1.457, g=208.455	0.83	0.19328	0.18679
Midilli et al	MR = a exp(-ktn) + bt	k=1.061E-5, a=0.957,b=0.003, n=5.01	0.994	0.03328	0.00332
		4%,5 min			
Newton	MR = exp(-kt)	k=0.081	0.68	0.22798	0.36381
Page	MR = exp(-kt^n)	k=7.33E-6,n=5.131	0.990	0.04593	0.01055
Modified page (I)	MR = exp(-(kt)^n)	k=0.1, n=5.131	0.991	0.04593	0.01055
Modified page (II)	MR = exp ((t/d^2)^n	d=205.7, n=-3.43E3	0.68	0.60664	0.22081
Henderson and Pabis	MR = a exp(-kt)	k=0.1, a=1.179	0.731	0.22598	0.30641
Logarithmic	MR = a exp(-kt) + c	k=9.95E-5,a=770.4 ,c=-769.3	0.868	0.37944	0.71987
Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.128,a=1.466,b= -0.466, k2=259.7	0.801	0.23775	0.22611
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.175, a=2.434	0.864	0.11945	0.08561
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.128, a=1.466, g=226.36	0.801	0.21265	0.22611

Midilli et al	MR = a exp(-ktn) + bt	k=1.171E-6, a=0.956, b=0.004, n=5.967	0.996	0.02513	0.00189
4%,10 min					
Newton	MR = exp(-kt)	k=0.109	0.739	0.21086	0.26677
Page	MR = exp($-kt^n$)	k=0.0013,n=4.166	0.993	0.04451	0.00792
Modified page (I)	MR = exp($-(kt)^n$)	**k=0.125, n=4.166**	**0.9933**	**0.04451**	**0.00792**
Modified page (II)	MR = exp $((t/d^2)^n$	d=-102.81, n=-1.157E3	0.739	0.66373	0.12027
Henderson and Pabis	MR = a exp(-kt)	k=0.13, a=1.165	0.781	0.21185	0.22441
Logarithmic	MR = a exp(-kt) + c	k=0.00019,a=476.4,c =-475.285	0.907	0.46397	0.86107
Two-term	MR = a exp($-k_1t$) +b exp($-k_2t$)	k1=0.176,a=1.559,b= -0.559, k2=4.12E7	0.864	0.21493	0.13858
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.226, a=2.446	0.908	0.12677	0.08035
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.176, a=1.559, g=209.988	0.864	0.29382	0.34532
Midilli et al		k=5.559E-5, a=0.966,b=0.005, n=4.762	0.997	0.04366	0.00572

❖ **At 70°C**

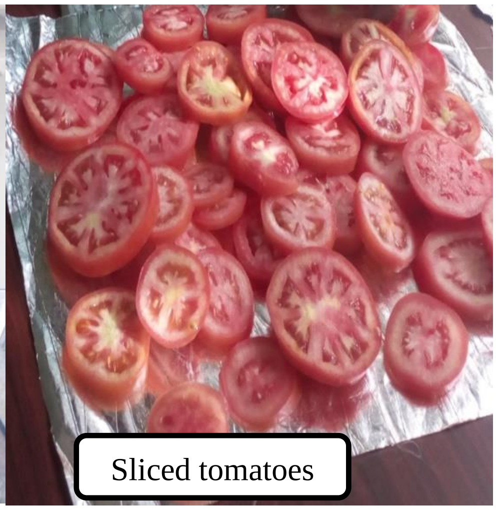
6%,15 min					
Model name	Model	constants	χ^2	RMSE	SSE
Newton	MR = exp(-kt)	k=0.11	0.741	0.22103	0.29313
Page	MR = exp($-kt^n$)	k=0.00018,n=4.128	0.992	0.0481	0.00925
Modified page	MR=exp($-(kt)^n$)	k=0.125, n=4.128	0.992	0.0481	0.0092

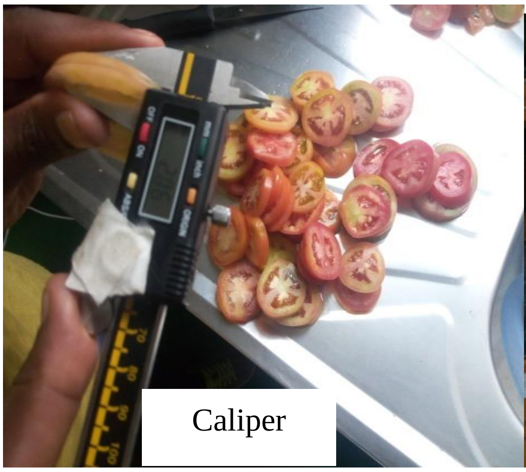
(I)			3		5
Modified page equation (II)	MR=exp((t/d^2)^n	n=-5.303, d=-7.029	0.722	0.25009	0.31271
Henderson and Pabis	MR=a exp(-kt)	k=0.13, a=1.164	0.782	0.2229	0.24843
Logarithmic	MR=a exp(-kt) + c	k=0.00018,a=498.9,c=-497.7	0.908	0.49248	0.97015
Two-term	MR=a exp(-k$_1$t) +b exp(-k$_2$t)	k1=0.176,a=1.556 ,b=-0.556, k2=831.377	0.866	0.23095	0.16001
Two-term exponential	MR = a exp(-kt)+(1 - a)exp(-kat)	k=0.223, a=2.454	0.894	0.13599	0.09246
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.327, a=136.146, g=0.331	0.908	0.22073	0.19489
Midilli et al	MR = a exp(-ktn) + bt	k=1.53E-5, a=0.963, n=5.378, b=0.005	0.997	0.02078	0.00086
		2%,5 min			
Newton	MR = exp(-kt)	k=0.11	0.742	0.18301	0.20096
Page	MR = exp(-kt^n)	k=0.000195,n=4.108	0.992	0.03674	0.0054
Modified page (I)	MR = exp(-(kt)^n)	k=0.125, n=4.108	0.9923	0.03674	0.0054
Modified page equation (II)	MR = exp ((t/d^2)^n	d = -90.435, n = 898.357	0.742	0.30178	0.45537
Henderson and Pabis	MR = a exp(-kt)	k=0.13, a=1.163	0.783	0.18194	0.16552
Logarithmic	MR= a exp(-kt) + c	k=0.00019,a=469.66,c=-468.5	0.909	0.47229	0.89222

Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.176,a=1.555 ,b=-0.555, k2=1000	0.866	0.3126	0.29315
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.735, a=2.439	0.909	0.20157	0.20315
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=-0.045, a=13.353,g=0.052	0.923	0.52254	1.0922
Midilli et al	MR = a exp(-ktn) + bt	k=5.8E-5, a=0.964,b=0.004, n=-4.97	0.997	0.13131	0.03449
		4%,10 min			
Newton	MR = exp(-kt)	k=0.155	0.797	0.19349	0.1872
Page	MR = exp(-kt^n)	k=0.002,n=3.483	0.994	0.04451	0.00594
Modified page (I)	MR = exp(-$(kt)^n$)	**k=0.166, n=3.483**	**0.9943**	**0.04451**	**0.00594**
Modified page equation (II)	MR = exp $((t/d^2)^n$	d=-38.133, n=-225.33	0.797	0.25277	0.25557
Henderson and Pabis	MR = a exp(-kt)	k=0.177, a=1.141	0.827	0.19991	0.15986
Logarithmic	MR = a exp(-kt) + c	k=0.001,a=156.9, c=-155.85	0.925	0.44769	0.60127
Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.177,a=0.963 ,b=0.178, k2=0.177	0.827	0.18283	0.06685
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.313, a=2.495	0.949	0.13917	0.07747
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=-0.03, a=-15.1, g=-0.024	0.916	0.25572	0.19618
Midilli et al	MR = a exp(-ktn) + bt	k=-0.697, a=1.199,b=-0.125, n=-99.97	0.925	0.225	0.05063

		2%,15 min			
Newton	MR = exp(-kt)	k=0.097	0.698	0.22535	0.30468
Page	MR = exp(-kt^n)	k=3.52E-5,n=4.773	0.987	0.05634	0.0127
Modified page (I)	MR = exp(-(kt)^n)	k=0.117, n=4.773	0.9873	0.05634	0.0127
Modified page equation (II)	MR = exp ((t/d^2))^n	d=139.8, n=-1.9E3	0.698	0.29188	0.42597
Henderson and Pabis	MR = a exp(-kt)	k=0.118, a=1.17	0.745	0.22697	0.25757
Logarithmic	MR = a exp(-kt) + c	k=0.00012,a=713.15,c=-711.99	0.881	0.4462	0.79639
Two-term	MR = a exp(-k_1t) +b exp(-k_2t)	k1=0.159,a=1.533,b=-0.533, k2=7.983E5	0.83	0.23919	0.17163
Two-term exponential	MR = a exp(-kt) +(1 - a)exp(-kat)	k=0.209, a=2.452	0.881	0.24704	0.30515
Verma et al.	MR = a exp(-kt) + (1 - a)exp(-gt)	k=0.159, a=1.533, g=219.978	0.83	0.22568	0.20373
Midilli et al	MR = a exp(-ktn) + bt	k=0.13, a=1.38,b=-0.112, n=-1.05	0.926	0.05766	0.00665

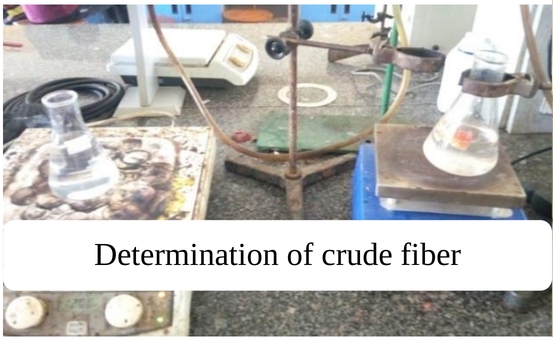
Appendix C: Experimental Pictures






Vitamin-C determination

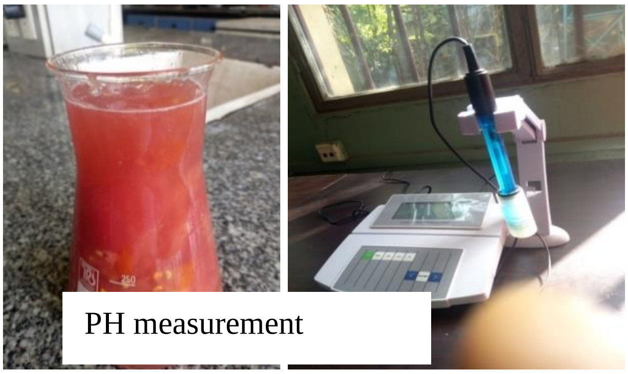

Colorimeter


Determination of crude fiber


Oven dryer


Determination of crude fat


Sample of dried product


PH measurement