Faculty of Engineering

DRYING KINETICS AND ANALYSIS OF TOMATO PEELS

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Dedicated to my beloved parents, family, and close friends, who always bestow me sustainable motivation and encouragements.

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ABSTRACT

Since tomatoes are one of the most commercially produced vegetables on the market, there is a good chance that wastage and losses may grow, especially during peak harvesting season. This is due to its high perishable characteristic that makes it to have a very limited shelf life when exposed to ambient temperature. The higher the moisture content, the higher the water activity will be, which then promote microbial spoilage. Due to this, food industry decided to turn fresh tomatoes into another processed products. However, based on research, it was detected that high percentage of tomato peels have been disposed during the products processing operation. Hence, the preservation of tomato peels through drying method offers another option in reducing the economic waste by turning it into an alternative product, such as thickening agent powder. Therefore, this study was conducted to study the drying kinetics of tomato peels, as well as other related conditions that could affect both its physical and chemical properties to determine its suitable oven drying conditions. It was found that the lowest to the highest amount of moisture lost during the drying were detected at the temperature of 50°C, 90°C, 70°C, 60°C, 100°C, and 80°C, accordingly. The highest to the lowest drying rate happened at the temperature of 80°C, followed by 100°C, 60°C, 70°C, 90°C, and 50°C, accordingly. It can be concluded that the best oven drying conditions for tomato peels in this study were found to be at the temperatures of 50°C with the range of drying time between 20 to 30 minutes, and 60°C with the range between 10 to 20 minutes, as these optimum drying temperatures showed a good performance in preserving the ascorbic acid content, as well as the quality of the colour and appearance. By controlling these drying conditions within the selected range, the desired removal of moisture content, the rate of drying, as well as the quality of dried tomato peels can be achieved.

Keywords: tomato peels, drying kinetics, oven drying, moisture content, colour

ABSTRAK

Memandangkan tomato adalah salah satu sayuran yang paling banyak dihasilkan secara komersial di pasaran, berkemungkinan besar pembaziran dan kerugian boleh meningkat, terutamanya semasa musim kemuncak penuaian. Ini disebabkan oleh ciri mudah rosaknya yang tinggi sehingga menjadikannya mempunyai jangka hayat yang sangat terhad apabila terdedah kepada suhu ambien. Semakin tinggi kandungan lembapan, semakin tinggi aktiviti air, yang kemudiannya menggalakkan kerosakan mikrob. Disebabkan ini, industri makanan memutuskan untuk menukar tomato segar kepada produk lain yang diproses. Bagaimanapun, berdasarkan kajian, didapati peratusan tinggi kulit tomato telah dilupuskan semasa operasi pemprosesan produk. Oleh itu, pengawetan kulit tomato melalui kaedah pengeringan menawarkan pilihan lain dalam mengurangkan sisa ekonomi. Oleh itu, kajian ini dijalankan untuk mengkaji kinetik pengeringan kulit tomato, serta keadaan lain yang berkaitan yang boleh menjejaskan kedua-dua sifat fizikal dan kimianya untuk menentukan keadaan pengeringan ketuhar yang sesuai. Didapati bahawa jumlah kelembapan yang paling rendah hingga tertinggi yang hilang semasa pengeringan dikesan pada suhu 50°C, 90°C, 70°C, 60°C, 100°C, dan 80°C, sewajarnya. Kadar pengeringan tertinggi hingga terendah berlaku pada suhu 80°C, diikuti oleh 100°C, 60°C, 70°C, 90°C, dan 50°C, sewajarnya. Dapat disimpulkan bahawa keadaan pengeringan ketuhar yang terbaik untuk kulit tomato dalam kajian ini didapati pada suhu 50°C dengan julat masa pengeringan antara 20 hingga 30 minit, dan 60°C dengan julat antara 10 hingga 20 minit, kerana suhu pengeringan optimum ini menunjukkan prestasi yang baik dalam memelihara kandungan asid askorbik, serta kualiti warna dan rupa. Dengan mengawal keadaan pengeringan ini dalam julat yang dipilih, penyingkiran kandungan lembapan yang diingini, kadar pengeringan, serta kualiti kulit tomato kering boleh dicapai.

Kata Kunci: kulit tomato, kinetik pengeringan, pengeringan ketuhar, kandungan lembapan, warna

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Notations

C^*	Chroma
R^2	Coefficient of determination
ΔE	Colour difference
L^*, a^*, b^*	Colour parameters
M_C	Critical moisture content
k, k_0, k_1, g, h	Drying constant
t	Drying time
M_E	Equilibrium moisture content
$MR_{exp,i}$	Experimental moisture ratio
$MR_{pre,i}$	Predicted moisture ratio
W_f	Final mass
W_i	Initial mass
X_e	Moisture content at equilibrium condition
X_0	Moisture content with dry basis at initial time
X	Moisture content with dry basis at specific drying time
n, a, b, c, $\propto$	Model constant
z	Number of constants
N	Number of observations
X^2	Reduced chi-square
AIJD	Air-impingement jet drying
DR	Drying rate

HPD	Heat pump dryer
MR	Moisture ratio
NEB	Non-enzymatic browning
RMSE	Root mean square error
WWB	Wet weight basis

Chapter 1

INTRODUCTION

1.1 Background of Study

The fast growing of population and urbanization has been giving rise to the development of industrialization and agricultural activities. Without realizing it, the transformation of these aspects has led the issue of food wastage to rapidly increase day by day. For all the foods that have been yield for the purpose of man consumption, roughly one-third of it is wasted or considered as an excess (Ishangulyyev et al., 2019). The standard industrial habit of rejecting the by-products from food processing has caused huge problems in terms of socio-economic and socio environmental. This is mostly due to the insufficient infrastructure, lack of processing capacity, as well as the hard conditions of booming market contributed by the extreme challenges and trading barrier in the global agricultural markets. In food industries, the process of food modification and recovery is a very crucial aspect that should be taken into consideration. Basically, the major concerns of this aspect are to reduce the spoilage and increase utilization of food so that the waste management and environment pollution issues could be minimized. The most brilliant way to reduce the wastage of foods is by conducting the food preservation methods. According to Correia et al. (2015), drying process is categorized as a traditional preservation method and highly considered as the most uncomplicated and inexpensive compared to other methods.

In general, drying process is not only required in food industry, but it is also applied in other processing industries, varying from agriculture to chemical and pharmaceuticals. In food industry, the common reason for foods, especially vegetables and fruits, to spoil within a short time is due to the moisture content. Drying method is broadly utilized in the food industry as it is guaranteed that the shelf life of foods could be extend longer since it able to help in reducing the moisture content, which indirectly lower down the water activity. In the last few years, it is found that dried vegetables and fruits have the potential to increase the demand on the global market with noteworthy added value. Hence, many researchers have been studying the drying process of vegetables and fruits to observe its effects in terms of the moisture content, colour, nutrients, flavour, and other more.

The drying of tomato has been taken to be one of the most studied subjects of expanded and assorted research works. Tomato, or scientifically named as *Solanum Lycopersicon*, is known as one of the world's greatest commercially produced vegetable with endless availability all year round since it is counted to be one of the most crucial horticultural crops worldwide (Gaware et al., 2010; Khazaei et al., 2008; Sadin et al., 2014). Several studies have proven that most countries tend to include tomatoes in their daily meals due to its health benefits towards human, such as nutrition rich that able to help in lowering down the risk of cancer and other diseases (Brooks et al., 2008). However, based on Kulanthaisami et al. (2010), there may be times where the market is oversupplied with fresh tomatoes during the peak season and causes huge volume of tomato gets damaged, which then leads to waste. To prevent this issue, tomatoes can be processed, preserved, and even sold at considerably low cost. Tilahun et al. (2017) stated that tomatoes are not only freshly consumed in raw form, but most of it can be seen to be consumed in some products that have been processed, such as paste, ketchup, juice, and other more. It is obvious that the process of producing tomato products surely involves the creation of wastage for some parts of the tomatoes, which are seeds, pulp, and its peels. Normally, tomato peels do not yield many benefits for food industries, which leads to more wastage issues (Selvaggi et al., 2021). Therefore, many studies found that the wastage of tomato peels could be reduced by drying method so that its shelf life can be extended and used in various culinary dishes, feeding livestock, as well as for agricultural usage.

In the study of food drying technology, the drying methods can be categorized into 2 types, which are conventional drying and advanced drying. Conventional drying is considered as the most common used method due to its simplicity, availability, and low cost. Meanwhile, advanced drying technology is known as the latest method developed with the purpose of improving the existed poor performance of conventional drying (Indiarto et al., 2021). This project is aimed to experimentally observe the drying kinetics of tomato peels by drying it out using conventional drying method. In consideration with the foregoing statements, the theory of drying kinetics and other related subjects will be further addressed in the next chapter. On top of that, the properties of the tomato peels with different moisture content will be determined in every specified time throughout the experimental work. Since temperature is highly involved in drying process, surely there will be an obvious impact on the moisture content and colour of the tomato peels. At the end of the observation, the outcomes will be analysed and discussed further in the results and discussion chapter.

1.2 Problem Statement

Being one of the major commercially produced vegetables in global market, it is fully guaranteed that the wastage and losses of tomatoes may have the potential to increase, especially during the peak harvesting season. This is due to its high perishable characteristic that makes it to have a very limited shelf life when exposed to ambient temperature. The higher the moisture content, the higher the water activity will be, which then promote microbial spoilage. Due to this, food industry decided to turn fresh tomatoes into another processed products. However, based on research, it was detected that high percentage of tomato peels have been disposed during the products processing operation.

Hence, the preservation of tomato peels through drying method offers another option in reducing the economic waste. There are various drying methods practiced by previous researchers, with companion of different types of dryer equipment. According to previous studies, it is understood that the usage of different types of dryer equipment with different temperature levels may provide both benefits and drawbacks towards the final quality of the dried tomato peels, in terms of physical and chemical modification. Therefore, the suitable drying conditions of tomato peels should be determined so it can be used as an alternative, such as thickening agent powder.

1.3 Research Questions

This study is mainly focusing on the analysis of oven drying of tomato peels and the research questions regarding this study are listed as below:

1. How is the performance of oven drying of drying tomato peels?
2. How does different moisture content influence the properties of drying tomato peels?
3. Does temperature give great impact towards the moisture content and colour of the tomato peels?

1.4 Aim and Objectives of Study

The main aim of this study is to determine the suitable oven drying conditions for tomato peels. There are three objectives have been focused on this study in order to accomplish the aim:

1. To investigate the kinetics of drying of tomato peels.
2. To compare the properties of drying tomato peels for different moisture content.
3. To study the effect of temperature on moisture content and colour of drying tomato peels.

1.5 Scope of Study

The drying method is applied in this study to analyze the drying kinetics of tomato peels to determine its suitable oven drying conditions. The term “drying kinetics” can be referred as the process of heat and mass transfer, macroscopically and microscopically, that occur throughout the drying operation. Basically, it is impacted by the drying circumstances, dryer equipment types, as well as the characteristics of the samples that required to be dried. It is usually conducted to determine and select suitable drying practices and to manage the drying operation. Next, tomato peels are chosen as the samples to be used in this study due to its high availability in the market and lower cost. The experimental work of this study is carried out at the Basic Chemistry Laboratory of Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, UNIMAS. All the result data obtained will be discussed according to the stated objectives of this study.

1.6 Research Gap

The conducted study is to investigate the drying kinetics occurred on the tomato peels throughout the drying process. The type of dryer used in this study is the oven dryer. The research gap of this study is that the topic of drying kinetics is broadly studied by using tomato slices or other types of vegetables and fruits, while the usage of tomato peels is very limited. Due to that, the findings and objectives from the past research works are also extended and slightly differ from the objectives of this study. Furthermore, the study of drying kinetics on tomato peels by using oven dryer at different temperature levels is also limited as most of the past research works focused on the usage of advanced dryers at specific temperatures.

1.7 Significance of Study

There are several significances that can be observed from the results obtained from this research project. The significances of study are listed as follows:

i. The in-depth understanding and the need to engage with drying kinetics knowledge in the research literature of the discipline.
ii. The in-depth analysis and the need to design suitable models related to the effect of temperature on moisture content and color of drying tomato peels.
iii. The interdependency in designing and using suitable equations related to the effect of temperature on moisture content and colour of drying tomato peels, as well as maintaining an environmentally friendly method of drying.

1.8 Summary

This chapter provides the general review on the study of tomato peels' drying kinetics. Basically, this study is conducted to observe the effect of temperature towards the moisture content and colour of the tomato peels, as well as to compare the properties of the tomato peels at different level of moisture content.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, all the related information regarding the kinetics of drying tomato peels is focused and discussed based on the research works that have been done by past and recent researchers. For the study of drying process, it can be found that there are several types of drying methods used to observe the drying kinetics of foods, especially vegetables and fruits. The most preferable technique for drying is the conventional drying technique, which is not only easy to conduct but also low cost. This method can be classified into 2 methods, which are natural drying and artificial drying methods. Natural drying depends on the sun as the source of heating, while artificial drying is depending on advanced mechanical and electrical equipment to generate heat. Due to several disadvantages of natural drying, the artificial drying is slowly getting the attention by many researchers to proceed with the study of food drying. Each of these methods could generate different results, in terms of quality of the dried foods, as well as the physical and structural changes due to different drying kinetics performance. Other than that, all the experimental works, equations, and simulation works conducted from past studies are also further presented in this chapter.

2.2 Theory of Drying Kinetics

Drying is one of the most broadly used method for preservation of foods. Not only that, but it can also be known as the most common and energy-intensive unit operation applied in various industrial areas, for instance, pharmaceuticals, agriculture, building materials, and other more. Basically, the elimination of moisture can be considered to occur due to the operation of synchronize heat and mass transfer. It is intentionally conducted to lower down the water activity in foods to an extent at which the growth of microbial, as well as enzymatic and degradation reactions are highly decreased.

Boekel et al. (2001) stated that, in order to determine the quality and the processing of foods, the modeling of kinetic process variables is extremely beneficial because it helps to predict and show the behavior or changes of the quality during the process, which comprises of various reactions chemically and physically, as well as its rates measurably. The mentioned changes will keep continuing with specific kinetics at a particular rate to generate either desired or undesired changes. Other than that, it also helps to understand the fundamental process of modelling and controlling the quality of foods. Note that, this theory indeed needed the understanding of thermodynamics and kinetics. Thus, in kinetics modelling, there are few main concepts that commonly applied to deeply understand the kinetics of foods and its processing.

The basic kinetic models involve simple, complex, and steady-state kinetics. It acts as a tool that could provide a better knowledge regarding the reaction's processes. In foods processing, enzymes, pH, and temperature are basically the factors that could affect the kinetics of reactions (Boekel et al., 2001). In this study, the impact of temperature is focused. In order to maintain the quality and shelf life of foods, temperature plays the crucial parts as most foods are heated or cooled. Hence, it is important to observe and understand how the heat treatment could influenced the quality of foods through the reaction kinetics. As discussed before, drying kinetics can be referred as the process of heat and mass transfer, macroscopically and microscopically, that occur throughout the drying operation. It is considered as a complicated and very difficult occurrence in food processing, while only few in literature for other products (Panda et al., 2019). Therefore, the understanding of drying kinetics is very useful in this case as it will help in knowing the proper drying operations for certain product, as well as able to control the drying process. Since it is very costly to perform a complete experiment regarding the determination of proper drying conditions, drying kinetics can be applied so that the process of eliminating the moisture with respect to the process variables could be observed and recorded. Also, the drying modelling can be constructed with the help of the drying rate obtained.

According to most of the research works that related to the drying of fruits and vegetables, the common factors that greatly influence the drying kinetics are the time taken and temperature applied for the drying process, surface area and the thickness of the food sample used, the velocity of air flow, relative humidity of air, type of dryer, and other more. Between these factors, the thickness of food sample and the temperature of drying applied are the most influential and highly studied factors in every drying kinetic research works (Abano et al., 2011; Correia et al., 2015; Khazaei et al., 2008; Sadin et al., 2014). For food products, the study of thin layer of the materials have been widely used by many researchers to describe the drying kinetic condition, accompanied with the mathematical modelling. Studies found that the reliance on the experimental drying method alone, without taking mathematical modelling of drying kinetics into account, could provide great impact on the dryers' efficiency, production cost, as well as the dried foods quality (Onwude et al., 2016). Therefore, it can be clearly seen that the application of mathematical models is very useful in predicting the drying kinetics, behavior, as well as the energy requirements during the drying process of food products.

2.3 Mechanisms of Drying

Traditionally, drying is referred as a unit operation that removing the water content of materials, which is from a high liquid or semi-solid material into a fully solid-dried material, through heating. According to Erbay and Icier (2010), the drying operation could happen in several different ways, such as the diffusion of liquid from pore surfaces, different moisture concentration that leads to liquid or vapor diffusion, as well as the force on the surface that leads to capillary action within porous materials. There are 2 common phenomena that can be used to describe drying operation, which are the constant rate period and multiple falling rate period (Inyang et al., 2018). Francis and Peters (1980) described the constant rate period as the moment where the diffusion rate of free water at the surface surpasses the rate of evaporation and the evaporation rate remains constant as the internal liquid transfer is adequate enough to sustain the saturated surface. As can be seen in **Figure 2.1**, segment BC is the constant rate period and point C in known as the critical moisture content (M_C), which is the point where the constant rate period ends, and the drying rate starts to decrease with time. Not only that, the consistency also can be seen from the surface temperature as the inlet energy rate is equivalent to the heat lost during the evaporation process. Barbosa-Cánovas et al. (2020) further stated that the rate of removing the water can be said to be controlled by not only from the evaporation rate between the surface and the drying means, but also influenced by the heat transfer rate to the surface of evaporation. Hence, it can be concluded that the constant rate period of drying is basically based on the surface rate that influenced by several external conditions, or also known as surface diffusion as the dominant mechanism.

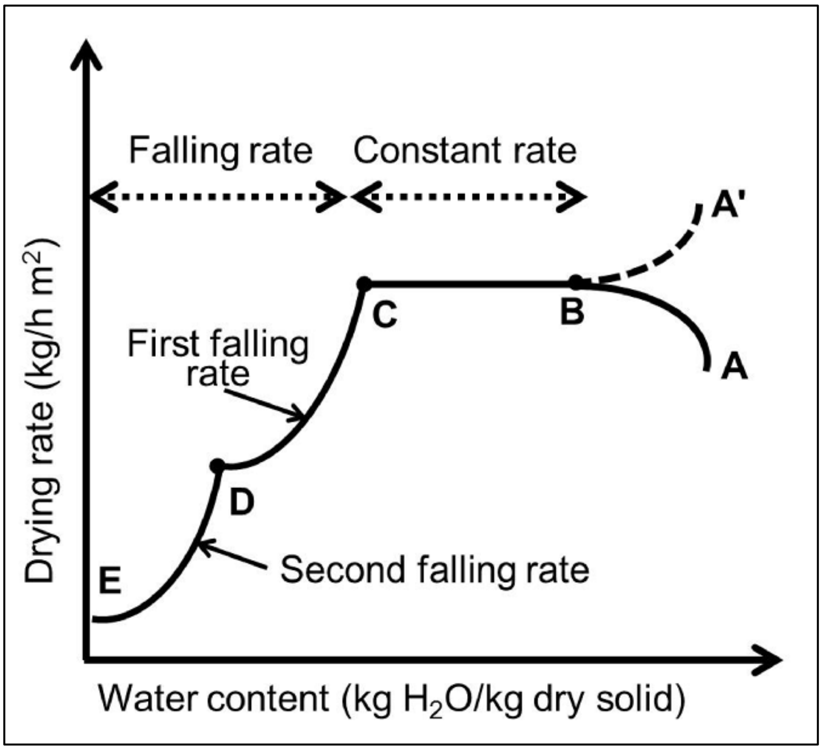

Figure 2.1 The rate of drying with respect to the moisture content (Silva et al., 2018).

In contrast, the falling rate period is referred as the period where the evaporation rate from the surface surpasses the diffusion rate from the inner area to the surface. Here, the material surface is also not in a saturated condition, hence, it can be said that the rate of drying is highly influenced by the rate of diffusion of the moisture through the material, or liquid diffusion as the dominant mechanism. Each of the falling rate period has its own causes to occur such that, the first falling rate period starts when the rate of drying reduces along with the moisture content because of the interior liquid diffusion resistance as well as the low heat flux into the materials. This period is illustrated at segment CD shown in **Figure 2.1** and point D is where the evaporation happens from the inner materials. Meanwhile, partial pressure is the main factor for the second falling rate period to occur. It started when the partial pressure of moisture in the material is lower than the saturation level. Basically, it is known as vapor diffusion due to the difference of moisture concentration, as well as the interior conditions of the materials. This period can be seen in segment DE, whereby the vapor pressure of the materials is equivalent to the partial vapor pressure of the drying air until there is no longer any drying occur. The equilibrium