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DISSERTATION

Experimental and modeling study of convective drying of tomato paste

submitted to the department of process engineering as partial fulfillment for the master degree in chemical engineering

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DEDICATION

I dedicate this humble work to my beloved mother

Rabha

And

To the loving memory of my father

Salem

And to all my family and friends

You been a constant source of support and

encouragement during the challenges of my life.

A. Madjid

DEDICATION

I dedicate this humble work to my parents

Abdelghani** and **Sabah

Who have always loved me unconditionally and

To all my family and friends

Without them, none of this work would be

possible.

A.Rahim

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Symbols	Designations	Units
V	Air velocity	m/s
Vs=dx/dt	Drying rate	kg water/kg dry matter.s
R	Universal constant of perfect gases	J/mol.K
a, b, c, n	Empirical coefficients in drying models	-
K, C	constants	-
R	Determination coefficient	-
S	Standards errors values	-
T	Temperature	°C
Θ	Temperature	°C
X	Moisture content	kg water/kg dry matter
T	Time	h
X_{eq}	Equilibrium moisture content	kg water/kg dry matter
X_m	Monolayer moisture content	kg water/kg dry matter
m_o	Initial wet mass of the product	kg
m_d	the dry mass of the product	Kg
Xi_{db}	Initial moisture content on dry basis	kg water/kg dry matter
m_w	Wet mass	kg
m_d	dry mass	kg
k, k0, k1	Empirical constants in drying models	-
XR	Moisture ratio	-
X_0	Initial moisture content	kg water/kg dry matter
m_w (t)	The wet mass values of the product must be recorded at different times	Kg

X(t)	Moisture content at the moment t of drying	kg water/kg dry matter
Y	Mass of water vapor at θºC	Kg
Cp_a	Massive heat of air	$J.kg^{-1}.C^{-1}$
Cp_e	Mass heat of water	$J.kg^{-1}.C^{-1}$
H	The enthalpy of moist air	$J.kg^{-1}$
db	Dry-based water content	-
W_b	Moisture-based water content	-
Lv	The latent heat of vaporization of water at 0ºC.	$J.kg^{-1}$
Ω	Absolute humidity	kg water/kg dry matter
pH	Potential hydrogen	-
P	Indicates the total air pressure	Pa
P_{vap}	The partial pressure of water vapor	Pa
HR	Relative humidity	%
ΔE	color distance	-
P_s	pressure of water vapor	Pa
T_s	surface temperature	°C
Aw	Water activity	-
P_{sat}	Saturation pressure	Pa
ΔX	The water content difference	kg water/kg dry matter
Δt	The time difference	h
exp	exponential function	-
Ln	*logarithm* napery	-
PV	Photovoltaic	-
IPGRI	International plant genetic resources institute	-
FAO	Food and Agriculture Organization	-

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Introduction

Introduction

Tomatoes are one of the most important grown vegetables crop in the world. According to (FAOSTAT 2014), the universal production of tomato on 2014 is 170.750.767 million tons; whereas Algeria produced 1.065.609 million tons with a world rank of 18 and a world share of 0.6%. In particular, 90% of world output is produced in the northern hemisphere (Mediterranean area, California and China). Tomato is cultivated in more than one hundred countries, both for fresh consumption and for industrial processing.

The industrial processing of tomato leads to a great variety of output products. Some of the most relevant are the following: concentrated tomato products, either as puree or paste depending on the percentage of natural soluble solids; pizza sauce, from peels and seeds; tomato powder, as dehydrated concentrated tomato; peeled tomato, either whole or diced; ketchup, tomato sauce seasoned with vinegar, sugar, salt and some spices, etc.

It is highly seasonal and available in large quantities at a particular season of the year. Due to market glut during peak season, large quantity of tomato gets spoiled. Preservation and storage of tomatoes during peak season can prevent the huge postharvest losses in tomato and make them available in the off-season at comparatively lesser cost. Tomatoes and tomato products are rich in health valued food components such as carotenoids (lycopene), ascorbic acid (vitamin C), vitamin E, folate and dietary fibers (Davies and Hobson, 1981; Raj Kumar, 2007).

Drying is one of the oldest techniques of preservation of food and agricultural products. The main objective of drying is to reduce the moisture content to the safe storage level, at which the products can be stored for a longer period without any deterioration or decontamination. The low moisture content prevents the growth of microorganisms such as moulds, bacteria, and yeasts, in the agriculture products and reduces the chemical reactions deteriorating quality of the products (Bahnasawy and Shenana, 2004). It also reduces the mass and volume of the products resulting in minimum packaging, storage, and transportation costs (Akpinar, 2006).

Demand for and acceptance of fresh tomato fruit are based largely on the flavor. Flavor is a composite of taste and odor (aroma), which are entirely different from physiological and chemical points of view. Taste is a function of the taste buds in the mouth; which constitute a selective mechanism. A relation exists between the kind of taste that a substance has and its chemical constitution. Based on psychological studies, the four primary sensations of taste are sourness of acids; saltiness of ionized salts; sweetness of sugars, glycols, alcohols, aldehydes, ketones, amides, esters, amino acids, sulfonic acids, and halogenated acids; and bitterness of long chain organic substances and alkaloids. Salty and sour tastes show a much better correlation with structure than do sweet and bitter tastes.

From the consumer's point of view, odor or aroma excites sensation in the brain when the aroma compounds contact the nasal cavity. The sensation depends upon the aroma substance fitting the olfactory cells in the nose. Fruit aroma is generally considered to consist of various volatile substances such as esters, aldehydes, ketones, alcohols, lactones, hydrocarbons, acids, etc., which exist in minute quantity in the fruit.

Tomato fruit quality is determined mainly by color, texture, and flavor. Among those, color and flavor are probably the most useful criteria for estimating maturity of tomato fruit. High quality is associated with redness of color and prominence of flavor. The flavor of a fruit becomes pronounced when the sugar content is at its maximum, at which time the skin acquires its richest color.

In the present study, in order to obtain a biological product from tomato paste, an experimental investigation has been conducted using a convictive dryer operating with controlled system. The main objective of this study is to study mainly the effect of drying parameters and define the optimal operating conditions to achieve best product quality and determine the suitable drying model.

The drafting of this work has been structured into, an introduction, four chapters and a conclusion. The first chapter discusses general notions of drying and the second chapter is an overview of the product to be dried. The third chapter presents experimental materials, equipment and a short presentation of the applied experimental design. Finally, all obtained results of the statistical analysis and mathematical modeling are discussed in the fourth chapter. The present study was completed with a general conclusion outlining the main results obtained through the different parts of this master thesis.

Chapter I

General drying notions

1.1. Introduction

In recent years, the postharvest losses of food and agricultural products have been reduced with the advanced preservation metho

ds. Drying is one of the oldest preservation methods used by human for industrial and agricultural products. This is the simplest and most cost-effective method among other preservation methods.

Drying is an operation intended to partially or completely remove water from a wet body by evaporation of this water so that bacteria, yeasts and molds can't grow and spoil food. Large quantities of products Foods are dried to improve shelf life, reduce packaging costs, reduce shipping weight, improve appearance, encapsulate original flavor and maintain nutritional value.

1.2. Drying technology

Drying is a key process in many food industries and in many agricultural countries. Large quantities of food products are dried to improve shelf life, reduce packaging cost, lower shipping weights, enhance appearance, encapsulate original flavor and maintain nutritional value. The primary objective of drying was to remove moisture from the food so that bacteria, yeast and mould cannot grow and spoil the food (Chou and Chua, 2001; Siqueira et al., 2012).

The drying process involves simultaneous: heat transfer from the surrounding to the surface of the product being dried combined with heat transmission within the material; and mass transfer from inside the product to its surface, followed by external transport of moisture to the surroundings (Discala and Crapiste, 2008).

1.3. Definition

Drying is a unitary operation that consists of removing all or part of a solvent (very often water) contained inside a wet body (solid or liquid). The final product obtained being always a solid.

1.4. Main agents of the convection drying operation

1.4.1 The product to be dried

The product to be dried is characterized by its initial mass m_0, initial water content X_0 which are determined experimentally. In order to follow the drying process, the wet mass values of the product m_d (t) must be recorded at different times t_i, and after knowing the measured dry mass, the water content as a function of time can be obtained on the wet or dry basis.

Moisture-based water content (w_b) or water content [Mennouche D. (2006)]: it is the mass of water contained in the product in relation to its wet mass.

$$X(t) = \frac{m_w(t) - m_d}{m_w(t)} \quad (1)$$

Dry-based water content (d_b) or moisture content [Mennouche. D, (2006)]: it is the mass of water contained in the product in relation to its dry mass.

$$X(t) = \frac{m_w(t) - m_d}{m_d} \quad (2)$$

Or: m_d: is the measured dry mass of the product, it is preserved during the drying operation and is calculated by the following formula:

$$m_d = \frac{m_0}{1 + X_0} \quad (3)$$

Or: m_0 is the initial wet mass of the product.

1.4.2 Wet air Enthalpy of moist air

The enthalpy of moist air defines the energy content of this air. The enthalpy noted H of 1 kg of dry air combined with Y kg of water vapor at θºC represents the amount of heat to be supplied to this mixture under a constant pressure for bring it from the reference temperature 0ºC to the temperature of θ°C. The reference states to consider are liquid water and dry gas at 0ºC. The enthalpy of moist air H is the sum of the enthalpy of air and the enthalpy of water.

$$H = Cp_a{}^{\theta} + Y\ (L_V + Cp_e{}^{\theta}) \quad (4)$$

Or: Cp_a and Cp_e are respectively the mass heats of air and water in the gaseous state and L_v is the latent heat of vaporization of water at 0ºC.

1.4.3 Temperature and humidity

The partial pressure of water vapor P_{vap} in the atmosphere is never zero whatever the place and the season, although its value can vary greatly.

1.4.4 Absolute humidity ω

It is defined for moist air (or other gases) as its moisture content. It is limited by the maximum quantity that the gas can absorb before saturation at the temperature of it.

$$\omega = 0.622\frac{Pvap}{P-Pvap} \Longrightarrow P_{vap} = \frac{\omega}{0.622+\omega}P \quad (5)$$

Where P: indicates the total air pressure**.**

1.4.5 Relative humidity (or degree of hygrometry)

Corresponds to the ratio of the partial pressure of water vapor contained in the air to the saturation vapor pressure (or vapor pressure), at the same temperature and pressure. It is therefore a measure of the ratio between the water vapor content of the air and its maximum capacity to contain it under these conditions. This ratio will change if the temperature or pressure is changed even though the absolute humidity of the air has not changed. Relative humidity is measured using a hygrometer. It is expressed most often in percentage and its expression becomes:

$$\text{Humidité Relative(HR)} = \frac{Pvap}{Psat(T)} * 100\% \quad (6)$$

1.4.6 Relation between relative humidity, absolute humidity and temperature [Jean Cstang, 2003]

$$HR = \frac{P}{Psat(T)} * \frac{\omega}{0.622+\omega} * 100\% \quad (7)$$

1.4.7 Expressions of calculation of P_{sat}

The approximate calculation of the saturation vapor pressure P_{sat} can be done using several formulas available in the literature such as:

- Dupré formula: [Yves Jannot (2005, a)] valid between -50°C and + 200°C to calculate P_{sat} (*T*):

$$P_{sat}(T) = \exp\left[46.784 - \frac{6435}{T+273.15} - 3.868 \ln(T + 273.15)\right] \quad (8)$$

Or :

T: Temperature in (°C).

$P_{sat}(T)$: saturation pressure in (mmHg).

- Rankine formula [Free Encyclopedia]: it takes the previous one with slightly different coefficients (deviation of 0.39 to 4.1% over the range of 5 to 140°C compared to the thermodynamic tables):

$$\ln(P_{sat}) = 13.7 - \frac{5120}{T} \quad (9)$$

With:

P_{sat}: saturation vapor pressure of water, in (atm).

T: absolute temperature, in (K).

1.4.8 Water activity in food

The a_w water activity is a classic quantity used to evaluate the ability of a product in a given atmosphere to degrade from a biological point of view. It corresponds to the ratio between the pressure of the water vapor of the food (pressure of the water vapor at the surface of the product) and the pressure of the pure water vapor at the same temperature θ_0.

$$a_w = \frac{\text{partial pressure of the water vapor of the food at } \theta}{\text{partial pressure of pure water at } \theta} \quad (10)$$

The activity of water in a product also represents the relative humidity of an air in equilibrium with the product (when there is no more exchange of water between them). The value of the water activity varies between zero (dry product to the point that all the water is linked to the food, and therefore without reactive quality) and 1 (pure water without solute, difficult to reach and above all to maintain).

The optimum value for the conservation of biological products, without additives or refrigeration, corresponds to a water activity of between 0.25 and 0.35; the growth of bacteria is generally limited when the water activity drops below 0.90 and the molds and yeasts are respectively inhibited to an activity of 0.70 and 0.80 [Jean-Jacques Bimbenet. 2002.Food Process Engineering RIA Dunod edition, Paris].

1.5. Drying Kinetics

The drying mechanisms are complex because several factors simultaneously affect the operation. These factors include the mode of drying and the characteristics of the product (nature, form and physical properties) [Benaouda N. (2006)]. These causes prevent finding a single model that can represent the drying kinetics in all situations. Drying rate $Vs = -dX / dt$ (kg of water per kg of dry matter per unit of time) is the average of the ratio of the water content difference ΔX by the time interval Δt. It is the size that characterizes practically the pace of the transfer.

The drying speed is a function of many parameters, the most important of which are:

- The nature, porosity, shape and moisture of the product.
- The temperature, humidity and speed of the dryer gas.

1.6. Different phases of a convective drying

The drying kinetics of the various products are studied by curves representing the evolution of the drying rate as a function of time. These curves are generally obtained for different experimental conditions (temperature, hygrometry, air velocity, etc). They characterize the overall behavior of the product to be dried over time. All the drying work shows that these curves are distinguished according to the nature of the product. In general, there are three different periods that are characterized by a different behavior of the drying speed: if, in a drying operation, the mass of the product is measured at regular intervals, the so-called curve of the drying speed will be obtained. On this curve figure (I.1), we distinguish three regions explained as follows:

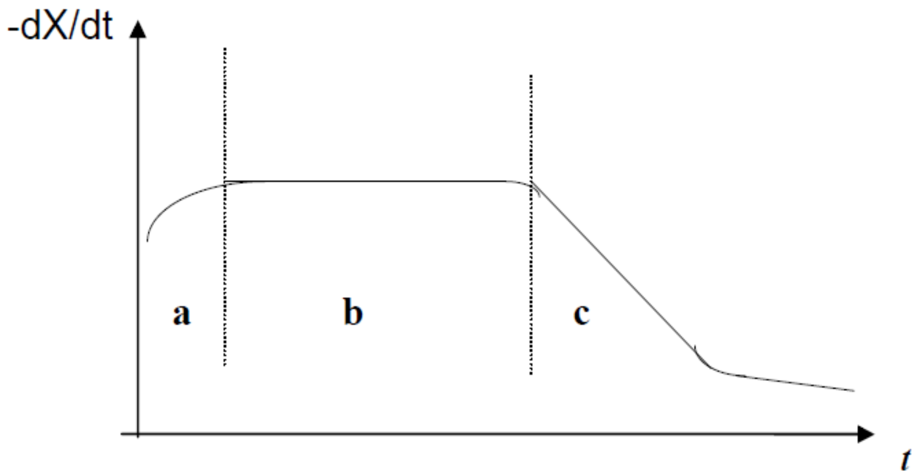


Figure I.1: Drying rate as a function of time.

- **Region a (Initiation or transitional period)**

This is the warm-up period. When a product of a surface temperature T_s and a partial pressure of water vapor P_s are stirred by a stream of hot air, exchanges of heat and material take place between the product and the drying air. To be carried as a vapor, the quantities of water contained in the product require a corresponding input of the vaporization energy. The excess heat provided by the air causes the product to heat up further resulting in a balance of the heat balance. If, on the other hand, the surface temperature of the product is too high, the energy deficit would lead to a cooling of the product. The warm-up period is short and really only appears if the products are large, or if the temperature difference between the air and the product is important.

- **Region b**

It is the period with a constant speed of drying; it exists only if the free water evaporates on the surface. The activity of the water on the surface of the product is then equal to one and the drying is called isenthalpic. For this period, it is possible to define the temperature of the wet thermometer. This is the temperature at which the inflow of heat entering is equal to the flow necessary for the evaporation of the water leaving the product.

- **Region c (Downturn period)**

This is the period with decreasing drying speed. The slowing down of the drying rate is explained by the following phenomenon:

Disappearance of free water in the product surface: this phenomenon corresponds to the beginning of the slowdown of the drying rate. Assuming that the migration of the free water and the bound water contained in the product takes place consecutively in liquid and vapor form, it is necessary to envisage the existence of a vaporization front which progressively sinks to the inside the product.

1.7. Influence of product characteristics to be dried on drying kinetics

- **The thickness of the product:** if this thickness is greater and greater, it means that the water vapor must cross a longer path and thus largely explains the slowing down of the drying rate.
- **The diffusivity (D) of the water in the product**: it varies with the water content of the product, the more it is dry, the less it becomes permeable to water. The mechanical strength of the intact cell walls prevents the water vapor from passing in large quantities outside the product.
- **Crusting:** some soluble compounds including sugars and salts accompany, the water evaporated during the period at steady pace (region b) and are arranged on the surface. This phenomenon called crusting is at the origin of high surface concentrations of these soluble compounds, which clog the pores of the product. The accumulation and drying of these solutes impregnate the surface of the product.

1.8. Influence of air parameters on drying kinetics

- **Influence of air temperature:** The drying air temperature has a considerable influence on the drying speed. This influence is due to the heat input to the product, which increases with the temperature of the air. It is also due to the temperature of the product, which is all the more important as the air temperature is high. As a result, the conductivities of the water in the product become important.
- **Influence of the air speed:** The speed of the air acts positively on the kinetics of drying especially at the beginning of the operation. However, in the case of products with poorly permeable skin, the influence of the air velocity is lower. This finding is reported by Belarbi (2001) in the case of drying dates.
- **Influence of air humidity:** The moisture content of the air plays an important role in the behavior of the drying kinetics of certain products. It seems that this influence is more important at the beginning of drying and decreases when the temperature of the air increases.

1.9. Drying systems

Because they are easy to use, very convenient, and the operating parameters can be completely controlled, variants of conventional drying processes, such as air-convective drying, sun drying and solar drying, are most commonly used with fruits and vegetables.

1.9.1 Open sun drying

This method of drying requires a large open space and long drying times. Although this traditional method requires only a small investment, open sun drying is highly dependent on the availability of sunshine and is susceptible to contamination from foreign materials (dust and sand) as well as insect and fungal infestations, which thrive in moist conditions. Such contaminations render the products unusable. Most agricultural and marine products require drying to preserve the quality of the final product, but open sun drying results in low-quality products.

Fish (Dilip Jain and Pankaj B. Pathare, 2006).

1.9.2 Convective drying

In this case, the air is heated by means of any heating source, and the hot air will be supplied to wet products to remove the moisture content. So, it is very important to understand the properties of air (Vega-Mercado et al. 2001 de Chapitre 1, Anil Kumar). A number of studies have addressed the issues associated with airflow drying. During this operation, there are changes in some important physical properties such as color (Chua et al. 2000), texture, and biochemical content, thus affecting flavor and nutrients. As a result, airflow-dried products have poor rehydration characteristics. The lengthy treatment at high temperature in numerous drying processes is an important cause of quality loss. Lowering the temperature has an enormous potential to improve the quality of dried products. Conversely, in low temperature conditions the operating time is too long and the associated costs too high. However, it is worth noting that airflow drying results in a wet bulb temperature that is lower than the temperature of the exchange surface. Nutrient content can be preserved and degradation is to a large degree located on the surface.

American ginseng (Hong-Wei Xiao et al., 2015), Deglet-Nour (Mohamed Hafed Berrebeuh et al., 2013), Gundeliatournefortii L (Duygu Evin, 2012).

1.9.3 Solar drying

This process is a technological process works on the principle of greenhouse effect (Pirasteh et al., 2014). This system which needs a simple technology allows to be adapted to the rural regions for drying applications (Alberto-Jesús Perea-Moreno et al., 2016), also in the most developing countries where supplies of non-renewable sources of energy are either unavailable, unreliable or, for many farmers, too expensive (Hernandez-Escobedo et al., 2015) this technology can be used. The produce is dried using solar thermal energy in a cleaner and healthier fashion. In broad terms, solar drying systems can be classified into two major groups namely:

- Passive dryer (conventionally termed natural circulation).
- Active dryer (most types of which are often called forced convection solar dryers).

Otherwise, according to the solar dryer types, there are four types of solar dryers (Chandra kumar B Pardhi et al., 2013).

1.9.3.1 Direct type solar drying

In these systems, the material to be dried is placed in a transparent enclosure of glass or transparent plastic. The sun heats the material to be dried, and heat also builds up within the enclosure due to the ‘greenhouse effect’. The drier chamber is usually painted black to absorb the maximum amount of heat.

Rehydrated Deglet-Nour Dates (Djamel Mennouche et al, 2014), tomatoes (Blake Ringeisen et al, 2014), chilli pepper (T.Y. Tunde-Akintunde, 2011), bitter gourd (Prashant singh chauhan et al, 2018).

1.9.3.2 Indirect type solar drying

The sun does not act directly on the material to be dried thus making them useful in the preparation of those crops whose vitamin content can be destroyed by sunlight. The products are dried by hot air heated elsewhere by the sun.

thymus and mint (A. A. EL-Sebaii and S. M. Shalaby, 2013), cocoa beans (Blaise Kamenan et al., 2017), red chili (Ahmad Fudholi et al, 2014), pistachio (Mohsen Mokhtarian et al, 2017), tomatoes (H. Bagheri et al, 2013), banana (Abhay Lingayat et al, 2017), granny smith apples (L. Blanco-Cano et al., 2016b), red chilli (Capsicum annuum L, costeño) (Margarita Castillo Téllez et al, 2017).

1.9.3.3 Mixed-mode drying

In this case, the combined action of the solar radiation incident on the material to be dried and the air preheated in solar collector provides the heat required for the drying operation.

Sultana grape and red pepper (Aymen ELkhadraoui et al., 2015), grapes (Chandra Kumar B. and Jiwanlal L., 2013), red peppers (Zaineb Azaizia et al., 2017).

1.9.3.4 Hybrid solar drying: In this type, although the sun is used to dry products, other technologies are used also to cause air movement in the dryers. For example, fans powered by solar PV, thermal storage systems.

Potato (Shobhana Singh and Subodh Kumar, 2013; Amin Ziaforoughi and Javad Abolfazli Esfahani, 2016), red chili (Tadahmun et al., 2016), tomato (H. Samimi et al., 2016), two types of residue, raw olive pomace and deoiled olive pomace (Abdelghani Koukouch et al., 2017), thyme (Lamyae Lahnine et al., 2016), peppermint (M.M. Morad et al., 2017), mushrooms (Alejandro Reyes et al., 2014), apricot (Ehsan Baniasadi et al., 2017), apple (Halil Atalay, 2017), bitter gourd (S. Vijayan et al., 2016).

1.10. Quality evaluation of agro-alimentary products

The quality of a foodstuff is a notion narrowly connected to the preferences and appreciations of the consumer, which explains the difficulty of giving a precise definition of it or of affecting standard criteria of evaluation of them. Quality is in fact a complex phenomenon which includes/understands the nutritive, sensory aspects and of hygiene (Baraem I et al., 2001).According to F J Francis (1995) the appearance of a product is the first impression which a consumer for a given food has. But appearance is an aspect of quality which contains several criteria of which the form, size, mass, volume, texture, color etc. The scientific work on the quality of the foodstuffs can be classified in three great directions, namely exploration of the consuming behavior, the characterization of the criteria of evaluation with the methods of measurements (instrumental and sensory) and in third place the exploitation of the first two directions to realize the follow-up and the quality control of the products during their natural development or in the course of various industrial processes(Thèse de Pr. Boubekri, 2010).

1.10.1 Color (hand book of food)

Color and color uniformity are vital components of visual quality of fresh foods and play a major role in consumer choice. However, it may be less important in raw materials for processing. For low temperature processes such as chilling, freezing or freeze-drying, the color changes little during processing, and thus the color of the raw material is a good guide to suitability for processing.

For more severe processing, the color may change markedly during the process. Green vegetables, such as peas, spinach or green beans, on heating change color from bright green to a dull olive green. This is due to the conversion of chlorophyll to pheophytin. It is possible to protect against this by addition of sodium bicarbonate to the cooking water, which raises the pH. However, this may cause softening of texture and the use of added colorants may be a more practical solution. Some fruits may lose their color during canning, while pears develop a pink tinge. Potatoes are subject to browning during heat processing due to the Maillard reaction. Therefore, different varieties are more suitable for fried products where browning is desirable, than canned products in which browning would be a major problem. Again there are two approaches: procuring raw materials of the appropriate variety and stage of maturity, and sorting by color to remove unwanted units.

1.10.2 Texture

The texture of raw materials is frequently changed during processing. Textural changes are caused by a wide variety of effects, including water loss, protein denaturation which may result in loss of water-holding capacity or coagulation, hydrolysis and solubilization of proteins. In plant tissues, cell disruption leads to loss of turgor pressure and softening of the tissue, while gelatinization of starch, hydrolysis of pectin and solubilization of hemicelluloses also cause softening of the tissues. The raw material must be robust enough to withstand the mechanical stresses during preparation, for example abrasion during cleaning of fruit and vegetables. Peas and beans must be able to withstand mechanical podding. Raw materials must be chosen so that the texture of the processed product is correct, such as canned fruits and vegetables in which raw materials must be able to be withstand heat processing without being too hard or coarse for consumption. Texture is dependent on the variety as well as the maturity of the raw material and may be assessed by sensory panels or commercial instruments. One widely recognized instrument is the tenderometer used to assess the firmness of peas. The crop would be tested daily and harvested at the optimum tenderometer reading. In common with other raw materials, peas at different maturities can be used for different purposes, so that peas for freezing would be harvested at a lower tenderometer reading than peas for canning.

1.10.3 Flavor

Flavor is a rather subjective property which is difficult to quantify. Again, flavors are altered during processing and, following severe processing, the main flavors may be derived from additives. Hence, the lack of strong flavors maybe the most important requirement. In fact, raw material flavor is often not a major determinant as long as the material imparts only those flavors which are characteristic of the food. Other properties may predominate. Flavor is normally assessed by human tasters, although sometimes flavor can be linked to some analytical test, such as sugar/acid levels in fruits.

1.11. Influence of pre-treatments and drying conditions on quality retention

Besides the activation and retention of bioactive compounds other quality attributes for dried products, like color, porosity, texture, flavor, have to be taken into account. It is therefore important to notice that drying is not the only unit in the chain of vegetable processing. It includes pre-treatment (washing, peeling, blanching etc.), drying and post-treatment (packaging, storage etc.). These treatments affect the quality attributes positively (digestibility, color bioavailability, Krokida et al., 2000) and negatively (breakdown of enzymes and micronutrients, Munyaka et al., 2010, Selman, 1994, Cieslik et al., 2007).

Chapter II

Overview on the product to be dried

2.1. Introduction

The tomato is a warm-season herbaceous, warm-climate plant species of the Solanaceae family, native to northwestern South America, widely cultivated for its fruit. The term also refers to this fleshy fruit, widely consumed in many countries, fresh or processed. Given its economic importance, it is the subject of much scientific research and is considered a model plant for scientific studies on fleshy fruits.

Tomato (Lycopersicon esculentum) is an important source of lycopene, which contributes to the prevention of many chronic diseases such as cancer and cardiovascular diseases. It also contains various nutritional sources (vitamins A, C and E, minerals and dietary fiber).

2.2. History

Tomato is the most commonly produced vegetable in the world (Ibrahim Doymaz, 2007). By use and culture, tomato is considered a vegetable. Botanically, however, it is a fruit, and among the fruits it is a berry, because it is indehiscent (non shedding), pulpy, and has one or more seeds that are not stones. The main commercial tomato cultivars are globular or oblong, but some special types may be elongated or pear-shaped. It was consumed by the Aztecs. It was introduced in Europe at the beginning of the 16th century by the Spaniards and then crossed the European borders. Recipes were developed in the Mediterranean countries, while in the countries of northern Europe; it was rather considered an ornamental until the eighteenth century. This fruit gradually became part of many dishes. In the twentieth century, the tomato industry gradually developed to offer more and more diversified tomato products.

2.3. Tomato varieties

Tomato is an indeterminate plant, but there are growing varieties to determine (zidani, 2009). The tomato is made up of two great botanical varieties that are (IPGRI, 2009):

- Solanum lycoperiscum esculentum with large fruits is the cultivated tomato from which derives almost all varieties or cultivars found on the market.
- Solanum lycoperiscum cerasiforme, or the cherry tomato, is the only wild form of the genus found outside South America.

In general, tomato varieties are classified according to their shape (figure 2.1) Counted:

- The varieties of flat and ribbed fruit, tomato type Marmande.
- Rounded fruit varieties.
- Fruit varieties elongated with a rounded tip (Roma type) or pointed (Chico type).
- Berry varieties: cherry tomato, cocktail.

- Varieties of diversification.

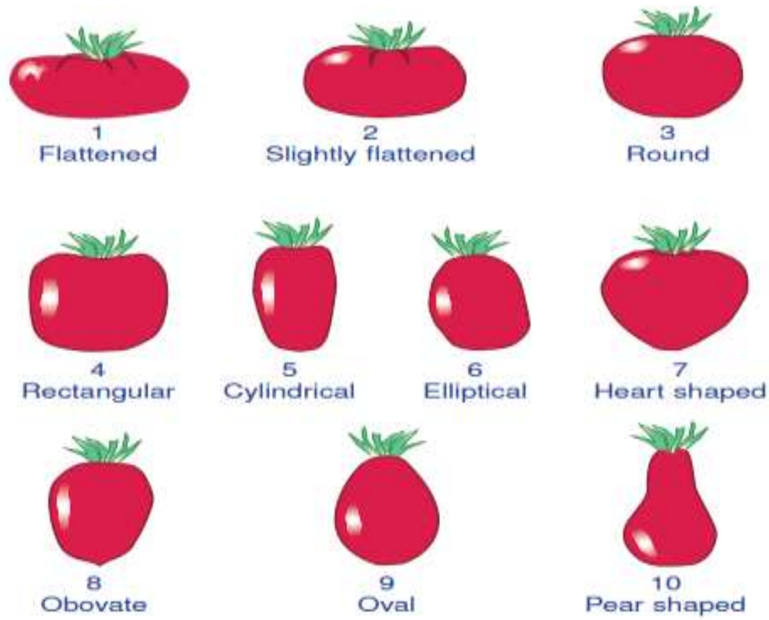


Figure 2.1: Morphology of tomato fruit (longitudinal section) selected by the International Union for the Protection of New Varieties of Plants (UPOV, 2001).

In General, the cylindrical (5) or oval (9) shaped varieties are used for drying. However, in our study, we used varieties of rounded shape (Kisselmina Kone, 2011).

2.4. Socio-economic context

2.4.1 Production

The cultivation of tomato (Solanum lycopersicum) is widespread throughout the world. According to (FAOSTAT 2014), the universal production of tomato on 2014 is170.750.767 million tons, whereas Algeria produced 1.065.609 million tons with a world rank of 18 and a world share of 0.6%. In particular, 90% of world output is produced in the northern hemisphere (Mediterranean area, California and China).

2.4.2 Consumption

The industrial processing of tomato leads to a wide variety of output products. The most important products are: tomato concentrate products, pureed or paste, based on the percentage of natural soluble solids; pizza sauce, from peels and seeds; tomato powder, as dehydrated concentrated tomato; peeled tomatoes, whole or diced; ketchup, tomato sauce seasoned with vinegar, sugar, salt and some spices, etc. (A. Ruiz Celma et al., 2013).

2.5. Structure and compositions

2.5.1 Structure

This fruit consists of three parts: the pericarp (including the skin and the fleshy part), the gel contained in the boxes and the seeds (figure 2.2). The skin consists of four to five layers of epidermal orhypodermic type cells under a fine cuticle.

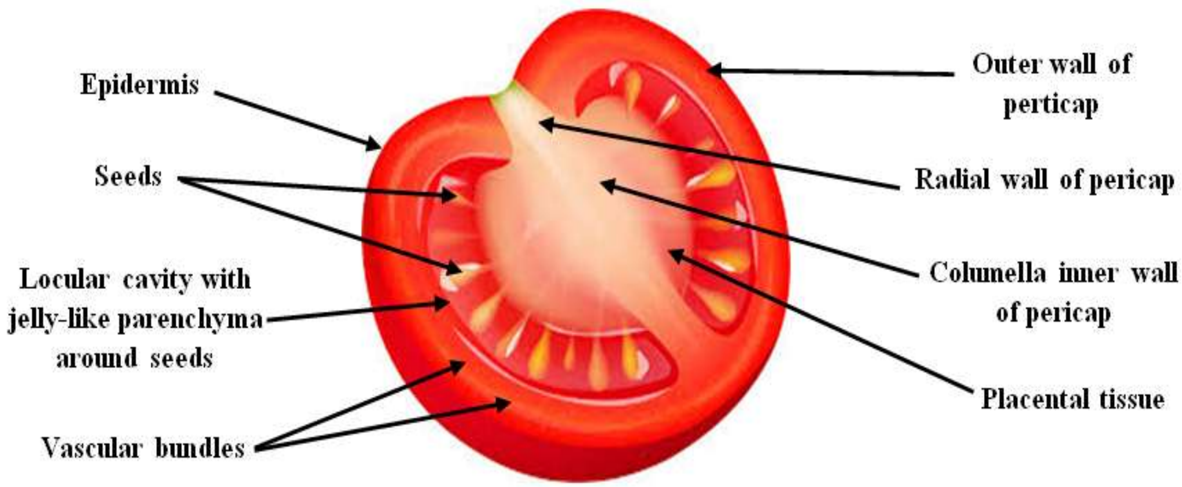


Figure 2.2: Transverse sections of mature tomato fruits showing the main anatomical features.

The nutritional value of the tomato is not very high in itself. Its relative concentration of vitamins and minerals makes it the 16th largest vegetable and fruit. However, its high consumption gives it the first place in USA for the total contribution in these elements in the food.

The biochemical composition of the tomato depends on several factors namely variety, season, maturity, cultural practices, soil, light and irrigation

2.5.2 Composition

2.5.2.1 Major components

Unlike most fruit, the tomato is a high energy food, because taken raw, it brings about 15 Kcal / 100g and 20 Kcal / 100g in the cooked state. The tomato as most of the vegetables: present a good nutritional density with: 94% water and 60% of dry matter composed of sugars (fructose and glucose), 25% acid 50 organic (acid citric and maliques), 8% of minerals, 2% of amino acids of carotenoids and other secondary metabolites, it is also a source of fibres (2g / 100g) is the quarter of nutrient intakes recommended (Davies and Hobson, 1981).

2.5.2.2 Minor components

The tomato contains many minerals and trace elements and like most fruits and vegetables, it brings a lot of potassium (245 mg / 100g) making it a significant source of this important mineral. It can also provide 50 to 160 mg of vitamin C and 22.5 to 90 mg of vitamin E. Among the phyto-components, it contains of poly-phenols (ferulique acid, cafeique acid, chlorogenic acid), (Beecher, 1998) of flavonoids (rutin, the quercitrine, the Kaempférol and the naringenin), and carotenoids, especially the lycopene levels vary (table 2.1) according to the type of product manufactured (Markovic, Hruskar, and Vahcic, 2006). The table (2.1) below summarizes the biochemical and nutritive composition of 100g of raw tomato.

Table 2.1: average Nutrient Composition for 100g Raw Tomato. Source: canada file on nutrutional elements 2010.

Nutritional elements	(g)
Water	94.5
carbohydrates	3.92
Alimentary fibers	1.2
proteins	0.88
Lipids	0.2
Ashes	0.5

Vitamins	(mg)
Vitamin C (ascorbic acid)	18
Vitamin E (tocophérols)	1
Vitamin B3 (nicotinamide)	0.6
Vitamin B5 (pantothenic acid)	0.28
Vitamin B6 (pyridoxine)	0.08
Vitamin B1 (thiamine)	0.06
Vitamin B2 (riboflavine)	0.04
Vitamin B9 (folic acid)	0.02
Vitamin B8 (biotin)	0.001

Carotenoids	(mg)
lycopene	3
βcarotene	0.6

Minerals	(mg)
Potassium	237
Chlorine	51
phosphorus	24
Magnesium	11
Manganese	0.114
Sulfur	11
Calcium	10
Sodium	5
Iron	0.27
Zinc	0.17
Bore	0.1
Copper	0.059
Fluor	0.024
nickel	0.023
cobalt	0.009
chrome	0.005
iodine	0.002

Energy intake	
Kcal	18.00

Chapter III :

Material and experimental methods

3.1 Sample preparation

Fresh local tomatoes (L.esculentum) were bought at a local market in Ouargla, southern of Algeria. They were singled out one by one using a visual criterion like color, size, absence of physical damage and uniform maturation degree. Forty kilograms of Tomatoes were properly washed with running to remove skin, dirt and then cut into halves or quarters. After that, it was grinded in a kitchen blender and separated in a whole series of sieves with different sizes to remove the skin and the seeds from the paste. Finally, the paste was drained in tissue bag to obtain 4 kilograms of tomato paste, 15 liters of tomato juice. The tomato paste was sealed in plastic bags and stored at 4°C.

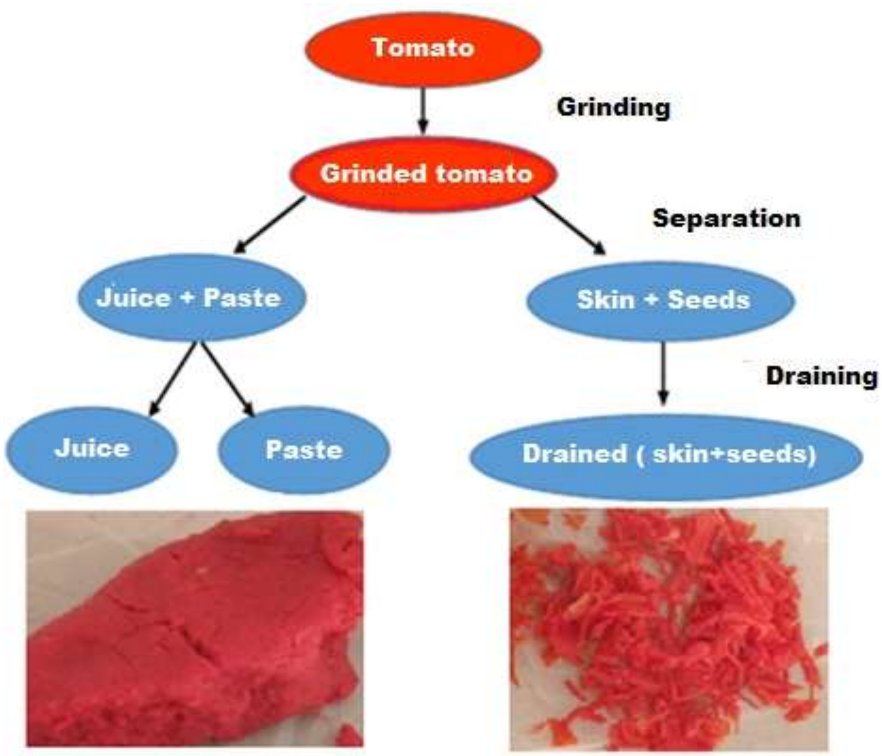


Figure 3.1: Samples preparation.

3.2 Initial moisture content determination

The sample’s initial moisture content was determined using a direct measurement method, which consists of placing a simple weight of 3grams in a Laboratory Incubator at 105°C (±1) °C for 24(h) until a constant weight is obtained.

Operating mode:

- Dry empty capsules in the incubator for 15 minutes at a temperature of 105°C.
- Tare capsules after cooling them in a desiccator.
- Weigh in each capsule 3 g samples and place them in the Incubator set at 105°C for 24 hours.
- Remove the capsules off the Incubator; place them in the desiccator and after cooling weigh them.
- Repeat the operation until a constant weight.

Figure 3.2: Drying oven (laboratory Incubator).

The initial moisture content is expressed on dry basis by the following formula:

$$Xi_{db} = (m_w - m_d) / m_d \qquad (11)$$

Where:

Xi_{db}: Initial moisture content on dry basis (kg water/kg dry matter).

m_w: wet weight in grams.

m_d: dry weight.

3.3 Color Measurement

Color measurements of dried tomato paste were done with Minolta CR-400 Chroma Meter (Minolta Co., Osaka, Japan). The CR400 Series Chronometers have a function (User Index) that allows the configuration of the evaluation equation and specific color calculation equations. This function responds to colorimetric control requests for which industry or specific evaluation formulas are used instead of the versatile color system and standards such as L * a * b *.

Figure 3.3: Chroma meter Minolta CR-400.

L*, a* and b* values were determined according to the CIE L*a*b* color coordinate system. This system, also known as the predominant scale used for fruits and vegetables. The CIELAB is a color space, as shown on figure (3.4), defined by the International Commission on Illumination (CIE) in 1976. It expresses color as three numerical values. L*, a* and b* values usually refer to brightness, redness and yellowness when the results obtained shows positive value; Vice versa, darkness, greenness and blueness is usually negative values. These color parameters (L*, a* and b*) are commonly functioned as an assessment indicator to the product quality. Color difference (ΔE*) were calculated by Equation (12).

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \quad (12)$$

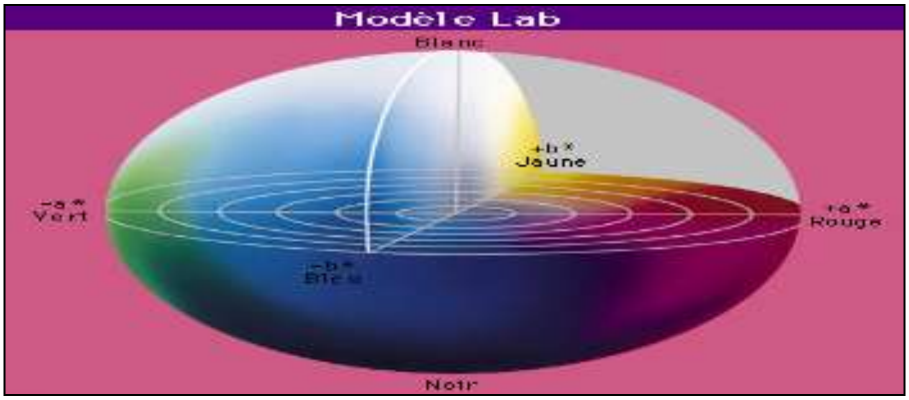


Figure 3.4: The CIE 1976 (L*, a*, b*) color space (CIELAB).

Operating mode

We have plugged the DP400 device into a power source. It is linked at the same time to a CR400 device; both devices are operating at position (1) "power (1)".

Place the CR400 on the plate and then click on the button "caliber" for the purpose of balance the device (CR400).

The CR400 is placed in the sample and then click on the measure button so the radiation emitted by the CR400 device strikes the sample. Finally, results are displayed at the DP400 device forms paper (the coordinates L*, a*, b*).

3.4 Drying equipment

Drying experiments were performed in a laboratory scale, convective and vertical downward flow dryer (designed and constructed in the LETTM laboratory, Sciences Faculty of Tunis). This dryer is designed to work in closed loop and was equipped with a programmable controlling system for drying air parameters. The layout of the dryer is given in figure (3.5).

3.5 Drying unit

The dryer is equipped with a controlling system for temperature, velocity and relative humidity of drying air and consists of a vertical airflow conducted through a tunnel to cross perpendicularly the tomato paste samples spread uniformly on a perforated tray (2 × 2 cm), placed inside the drying chamber figure (3.5.a, b). Moisture loss was obtained through periodic measuring the samples weight during drying which was recorded at 30 min intervals by means of a digital balance interfaced with a PC to insure the data acquisition.

Figure 3.5.a: Picture of the experimental laboratory LETTM dryer (Drying loop).

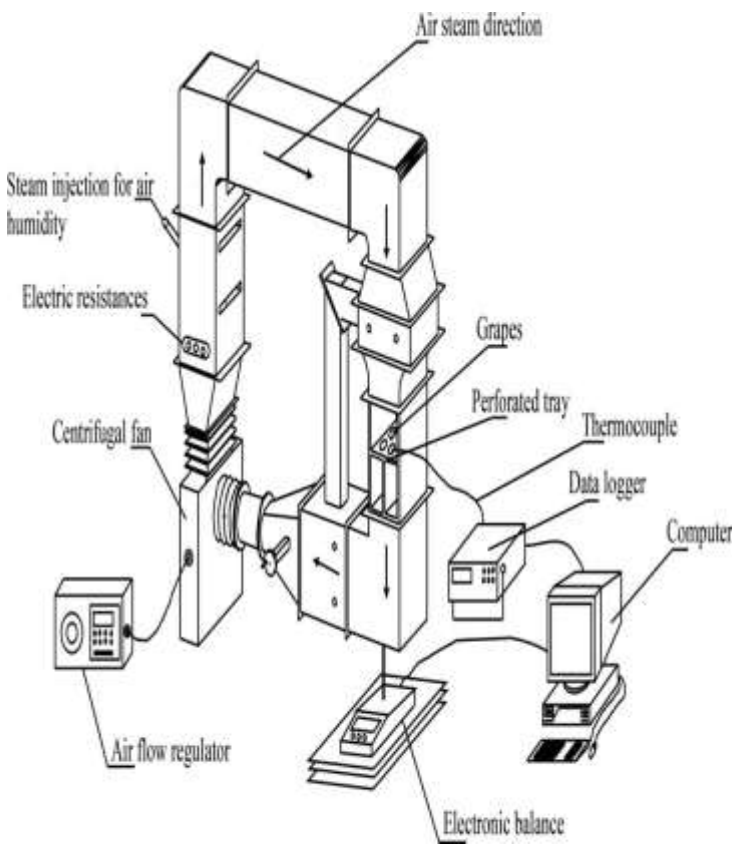


Figure 3.5.b: Overall layout of the experimental laboratory LETTM dryer (Drying loop).

3.6 Experimental procedure

Prior to start the drying experiments, the system was run for at least a quarter of an hour (¼ hour) to obtain steady state conditions. A batch of 50g of fresh tomato paste has been taken out from the refrigerator to rest. Samples were spread in a perforated tray (dimensions in cm: 2×2) in thin layer of about 1cm thickness. The tray loaded with tomato paste was suspended to a digital balance with a standard error of± 0.001 g. Air parameters were adjusted and controlled continuously using an industrial programmable controller. In order to guarantee dried product quality, experiments were performed in the temperature range from 45 to 60°C, in a relative humidity of 16 % at two air velocities: 1.5 and 2.5m/s. The mass of the product was continuously measured with constant time interval (30minutes) using an electronic balance (precision of 0.01g) and recorded by a microcomputer. the final moisture content should be lower than 0.13 (kg water/kg dry matter) in order to maintain dried products in a stable and low water activity state (D. Mennouche et al, 2017). The samples were dried until the final moisture content was less than 0.13 (kg water/kg dry matter).

3.7 Experimental design

3.7.1 The importance of experimental design methods

In a review of the literature published over the past 20 years, it was found (to the best of the knowledge of the authors) that the general issue of the relative influence of each parameter on convective drying performance has not been discussed, despite efforts to account for most design and operating parameters. This is most likely because evaluation and optimization of convective drying performance using classical experimental, analytical or numerical methods is a very complex task, given the large number of design parameters and operating parameters (air drying temperature, flow rate, wind speed, etc.) involved. The complexity is due mainly to the multiplication of interactions between these parameters. However, these parameters and their interacting effects do not all have the same level of influence on convective drying performance. A powerful and reliable decision-making method has therefore been proposed, namely the experimental design method. This method has gained a solid reputation in the field of control, modeling and optimization of complex systems. It provides the best possible information regarding parameter effects and overcomes the limitation of conventional methods by allowing evaluation of interactions between design and operating parameters with a minimal number of measurements.

3.7.2 Objective

The experimental design methodology is applied to drying filed to determine the optimum operating conditions that provide optimal drying performance and the influence of selected parameters the product’s quality.

3.7.3 Principle

The principal steps that should be followed in the design-of-experiments method are shown schematically in figure (3.6**)** and figure (3.7) (Goupy, 2005). Figure (3.6) presents the steps required to produce the planning matrix. For a successful experiment, it is crucial that potentially important parameters be identified at this stage. The next step is to specify an experimental range and a suitable level for each control parameter. This step is important because the use of an inappropriate experimental range or unsuitable parameter levels generally leads to results of poor quality and difficult to analyze (Wu and Hamada, (2009)). Once all of the parameters and their experimental domains have been identified, the next step is to prepare the list of experiments to be performed. This list, also called the planning matrix, must contain all of the possible combinations of the parameters evaluated at the three levels.

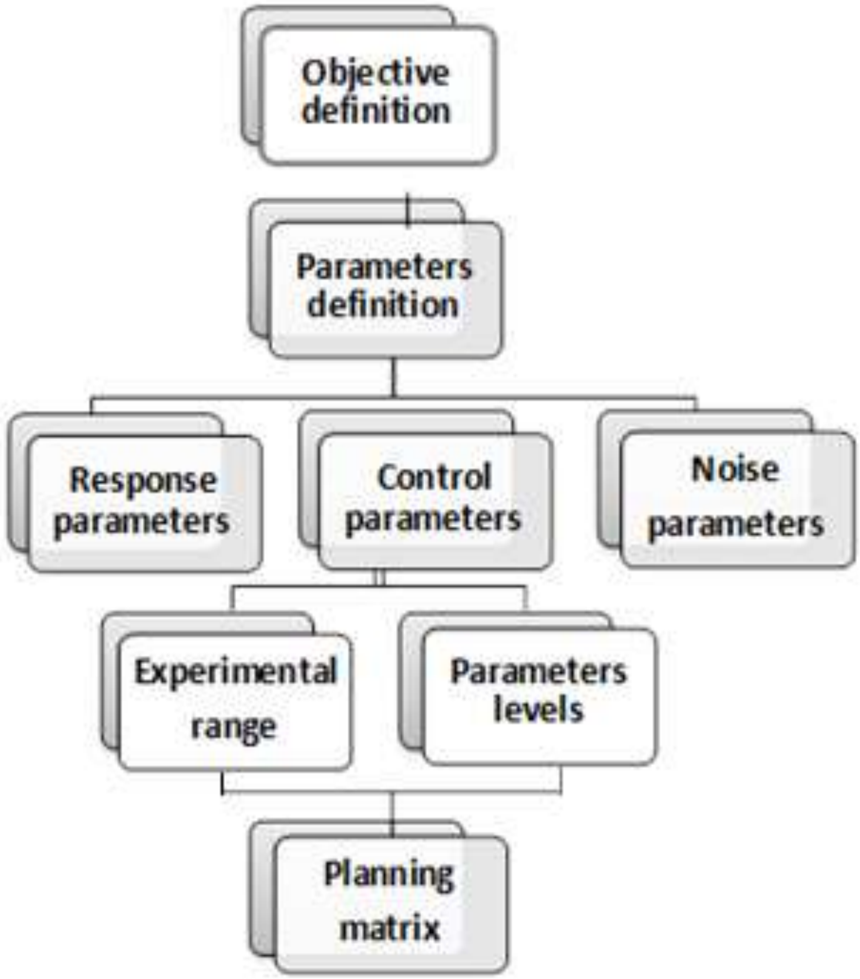


Figure 3.6: Schematic representation of the planning stage.

Figure 3.7 provides a schematic depiction of the steps required to optimize the efficiency of a convective drying once the planning matrix has been obtained. With appropriate planning, preliminary experiments can be carried out to obtain a suitable model. Once the experimental model has been determined, the optimal performance of the convective drying can be predicted for the specified parameter ranges.

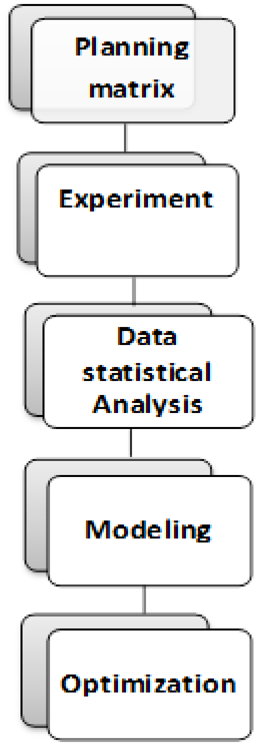


Figure 3.7: Schematic representation of the efficiency optimization process.

3.7.4 Statistical analysis

An experimental design should be designed as a means of determining factors or interactions that have a statistically significant influence on the response (s). Statistical analysis of the experimental results is often quite fast. Due to the use of dedicated software. The principle of statistical analysis is simple. It consists on calculating the coefficients of the polynomial model. The higher the absolute value of a coefficient, the more the corresponding term (simple factor or interaction) influences the response. To distinguish a true influence and the role of uncertainty is what makes it difficult.

At the conclusion of the study, we list only the influencing factors and express the model by retaining only the statistically significant coefficients. The obtained model worth noting if it wasn't used only within the range of study (hence the usefulness of a correct preliminary study): any prediction is very risky because it could bring very different results from those expected. Again, the provided model has no physical meaning and it cannot be equal to a physical law.

3.7.5 Statistical analysis using Statgraphics software

The analysis of the experimental results was done with an experimental design using Statgraphics Centurion XV software version 15 (MANUGISTICS Inc., Rockville, USA). We chose this software for the following reasons:

- Its intuitive user interface and dynamic data management reduces the amount of time spent analyzing data.
- Built-in help helps the user interpret the results as clearly and concisely as possible.
- Many graphical representations of results are available.
- The possibility to export the results to other applications.
- Tables summarizing analysis of variance (ANOVA), which is a methodology for analyzing the effect of qualitative factors on a response. An ANOVA breaks down the variability of responses according to different factors. Depending on the type of analysis, it may be important to determine: (a) the significant factors that affect the response and / or (b) the part of the response variability that can be attributed to each of the factors.
- Pareto charts that are frequently used to visualize significant factors.
- Graphical representations of the response variation as a function of factor levels. These representations make it possible, among other things, to highlight the importance of the nonlinearities of models.

3.7.6 The main steps for the construction and analysis of experimental designs

Step 1: Define the plan/planning matrix

The experiment plan is created by executing a dialogs series in the software. In these dialog boxes, the user defines the experimental factors and the responses, the experimental domain, the order of randomization and the existence of the blocks.

Step 2: Conduct the experiments

The experimental tests defined in step 1are implemented and the results were listed in the experimental plan spreadsheet (Data book).

Step3: Analyze the experiments

The ANOVA results represented in the form of the Pareto diagram are used to visualize the effect of each factor on the response.

Step4: Continue data analysis

The answers are analyzed and a statistical model is built. Usually the non-significant effects are excluded from the model.

Step 5: Optimize the answers

The optimal setting of factors is calculated to optimize the desired responses. If multiple answers are present, a desirability function is constructed. This function allows the optimization of a multi-objective problem. Some of these objectives being contradictory, it is a question of establishing a compromise.

3.8 Data analysis

The analysis was carried out with the statistical program (Statgraphics, Centurion XVI version 16.1.11 (32-bit), USA). It contains a wide variety of statistical procedures for addressing most data analysis needs. All The curves in parametric study were plotted with Origin Pro 2017 software. The mathematical modeling was carried out using (CurveExpert version 1.4).

Chapter IV

Results and discussion

4.1. Introduction

In this chapter, we presented the results of the drying experiments of tomato paste with a parametric study of different operating conditions. We then presented an explicit result of quality based on color measurements. Then we proceeded to an optimization study using a factorial design.We ended the present chapter by a mathematical modeling study with the aim to choose a suitable behavior model to describe the drying of tomato paste.

4.2. Experimental drying kinetics

The following table 4.1 shows the operating conditions of each experiment.

Table 4.1: Recap table of the operating drying conditions.

N°	Xi (kg water/kg d.b)	T(°C)	V (m/s)	RH (%)	m_w(g)
1	10.1	45	1.5	16	50
2			2.5		
3	10.1	50	1.5	16	50
4			2.5		
5	10.1	60	1.5	16	50
6			2.5		

In table 4-1, $\mathbf{X_i}$ is the initial moisture content and $\mathbf{m_w}$ is the mass of the wet product.

4.2.1 Example of experimental drying kinetics

The moisture ratio of the tomato samples as a function of drying time is shown in figure (4.1). As expected, the moisture content decreased considerably with increasing drying time. The time required to reduce the moisture content to the desired level was dependent on the drying conditions, being highest at 60°C and lowest at 45°C. With drying, the time taken to reduce the moisture content of tomatoes from the initial value 10.1 kg water/kg (d.b) to a final value 0.13 kg water/kg (d.b) was 11.16 h at 45°C. The effect of drying air temperature was most dramatic with moisture content decreasing rapidly with increased temperature. Several authors reported that drying rates increased with the increase in temperature for drying various vegetables such as pumpkin, eggplant, and okra.

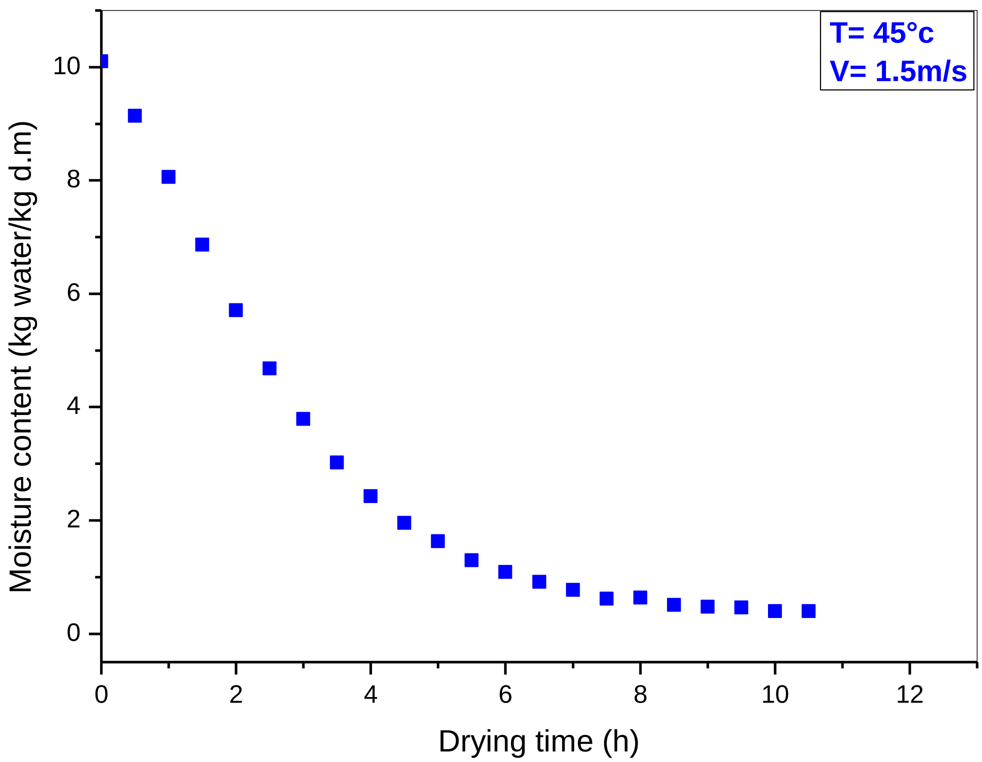


Figure 4.1: Time evolution of the average moisture content.

4.3. Parametric study of tomato paste drying

4.3.1 Effect of drying air temperature

The experimental curves in figures (4.2.a,b) show that increasing air temperature from 45 to 60°C decreased significantly the drying time (11.16 h, 10.45 h, 7.5 h) to air temperature 45, 50, and 60°C respectively, for air velocity of 1.5 m/s. This influence is due to increasing in the partial vapor pressure of water in the product. Also an increase in air velocity from 1.5 to 2.5 m/s decreases relatively the drying time as a result of increasing convective heat and mass transfer coefficient between the drying air and the product (for T = 45°C drying time is 11.16 h and 9.62 h, respectively, to 1.5 m/s, 2.5 m/s (air velocity). For T = 50°C it is 10.45, 9.10 hours respectively.

Finally for T = 60°C it fell down to 5.73 h, 5.32 h. Therefore, there is a strong function of temperature and relatively weak function of air velocity. As it was expected, during the initial stages of drying there was a rapid moisture removal from the product (slope of moisture curve in figures (4.2.a, b) is much higher in the beginning of drying process) which later decreased with increase in drying time.

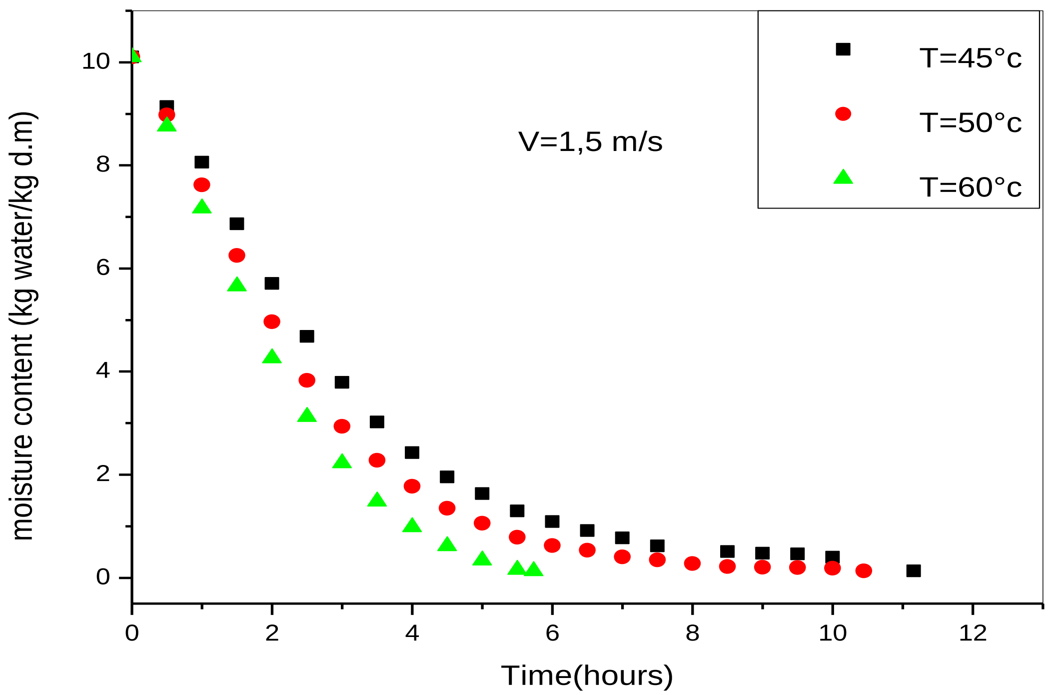


Figure 4.2.a: Effect of drying air temperature at V=1.5m/s on drying kinetics of tomato paste.

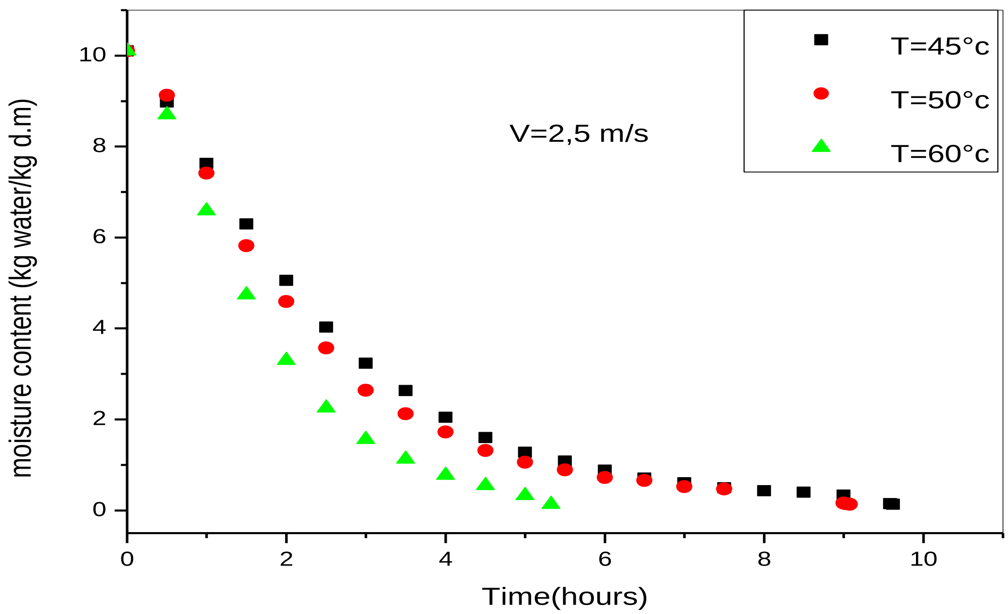
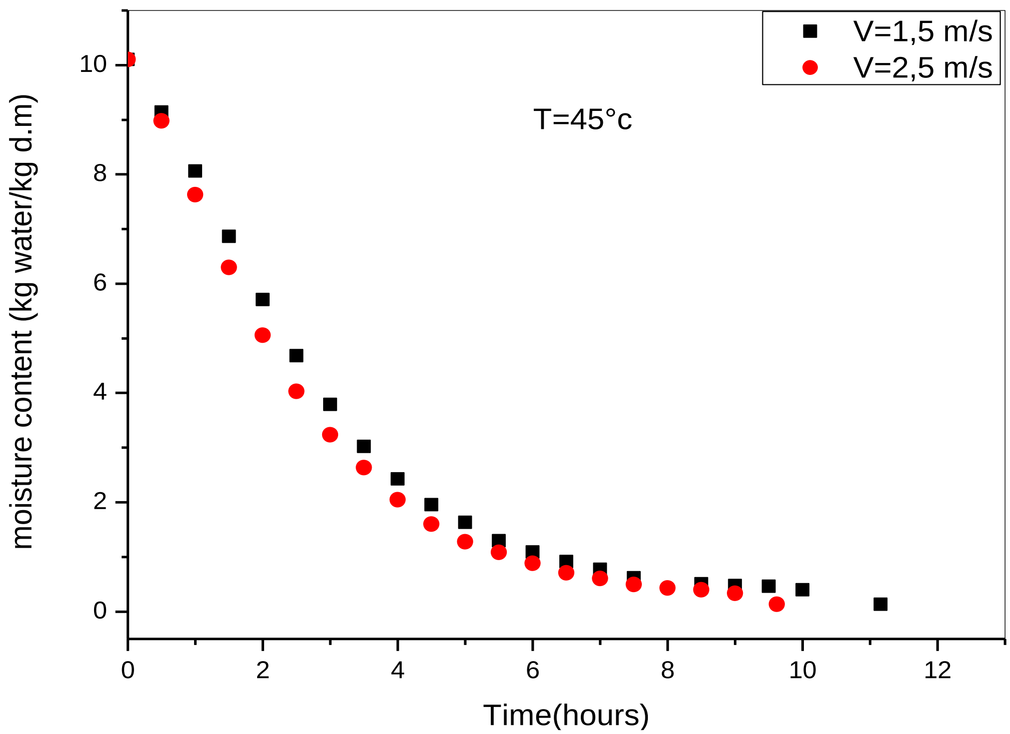


Figure 4.2.b: Effect of drying air temperature at V=2.5m/s on drying kinetics of tomato paste.

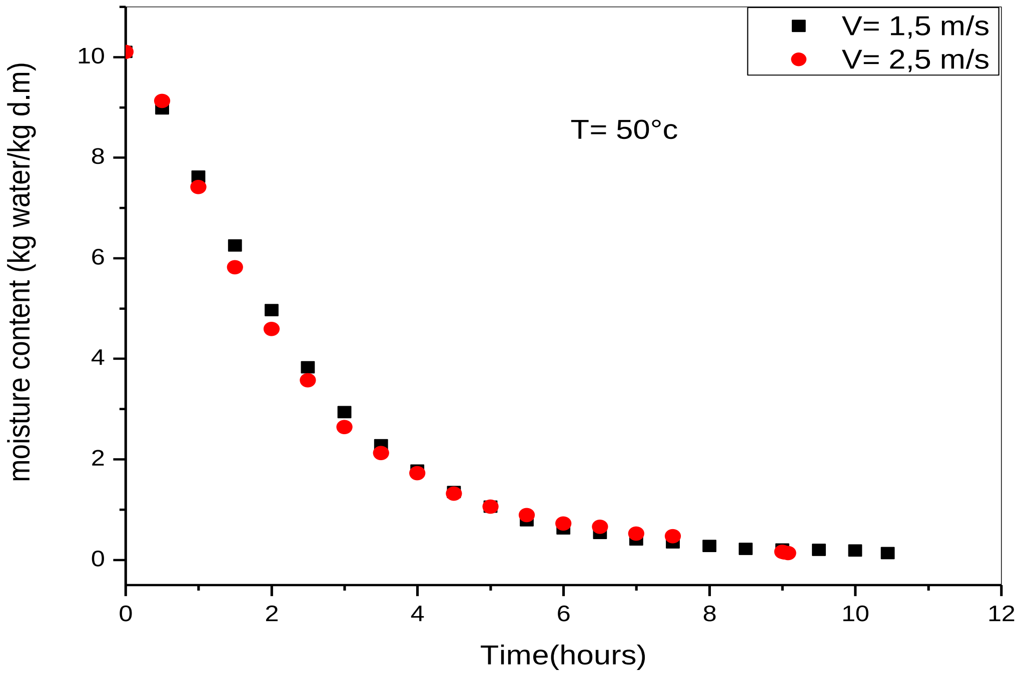
The good process of food drying is to remove moisture as quickly as possible to prevent mold and to conserve organoleptic characteristics. We choose a suitable temperature that does not seriously affect the flavor, texture and color of the food. If the temperature is too low in the beginning, microorganism may grow before the food is adequately dried. If the temperature is too high and the humidity too low, the food may harden on the surface preventing moisture to escape and the product does not dry properly. High temperature or long drying times cause serious damage to product nutrients (pigment degradation like lycopene and oxidation of ascorbic acid) and reduce the rehydration capacity of the dried product (Lin and al. (1998)), (Drouzas and al. (1999)). The loss of ascorbic acid is dependent on the drying temperature used and the moisture content in the final product; for instance, tomatoes dried at 80 °C contained 10% residual ascorbic acid while those dried at 110 °C contained none (Zanoni and al. (1998)). For all these parameters cited above and for energy saving and drying time reducing and for visual aspects, drying tomato paste at T =45°C, V=2.5 m/s was found to be the best choice in terms of color and shape.

4.3.2 Effect of airflow velocity

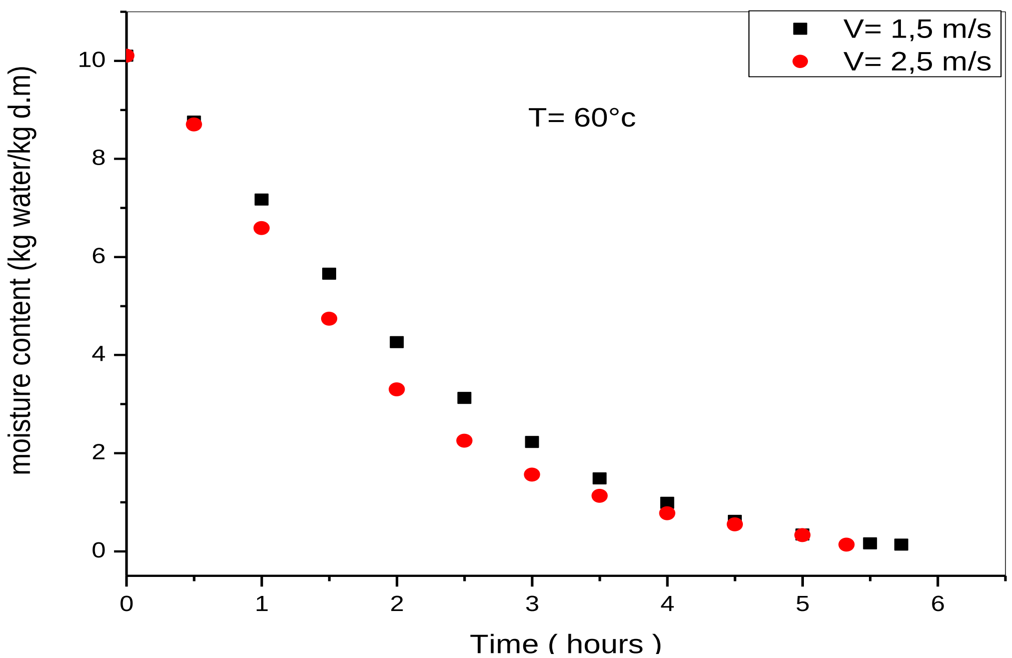
By observing the effect of air velocity on drying kinetics figures (4.3.a, b, and c), the results show a slight effect of air velocity at low temperatures compared with high ones. The effect of air velocity increases with increasing drying air temperature. S, Boughali. and al. (2009) confirmed that the air velocity is not as influential parameter as the drying air temperature and the influence decreases with drying process increasing.



Figures IV.3.a: Effect of air velocity at T=45°C on drying kinetics of tomato paste.



Figures 4.3.b: Effect of air velocity at T=50°C on drying kinetics of tomato paste.



Figures 4.3.c: Effect of air velocity at T=60°C on drying kinetics of tomato paste.

4.4. Results of Color measurement

Table (4.2) shows the results of color measurement L*, a*, b* and a*/b* for all dried samples. Color change is a quality criterion for assessing the quality of dried products. The closer it is to the fresh tomatoes, the more desirable it is for consumers. Higher values of brightness (*L**) and ratio of redness to yellowness (*a**/*b**) are desirable in dried products (Arslan and Özcan 2008).

We observed that the brightness of the tomatoes increased from 43.69to 45.94within the studied temperature and velocity range of 45-60 °C and 1.5-2.5 m/s, respectively. The redness, decreased from 15.19 to 16.34 while the yellowness also increased from 34.53 to 37.19 within the same ranges.

This result shows that drying conditions T= 45°C, V= 2.5 m/s for air temperature and air velocity respectively, are best to retain the red color quality of tomato paste.

Table 4.2: Results of color measurement.

N°	V (m/s)	T (°C)	L*	a*	b*	a*/b*
1	1.5	45	43.86	24.67	15.19	1,624095
2	2.5	45	43.69	24.91	16.17	1,540507
3	1.5	50	45.32	23.53	15.11	1,557247
4	2.5	50	44.09	23.74	14.63	1,622693
5	1.5	60	44.04	22.1	16.1	1,372671
6	2.5	60	45.94	23.84	16.34	1,458996

4.5 Optimization of the Drying Process

In objective to search the optimum conditions for drying tomato paste and to study the effect of those conditions on each of drying time (t) and color stability (L*, a*, b*) of convective drying of tomato paste, we used an experimental design method through five complete factorial designs. The available literature presents the air temperature (T) and the air velocity (V) as the main influence parameters often considered in the drying of tomato paste. Adopted parameters, according to the proposed experimental design, are defined as follows: factor one (V): air velocity; factor two (T): air temperature. The response

Y_1, Y_2, Y_3, Y_4 then represents L*, a*, b* and drying time respectively. Knowing that the general formula of the number of experiments (N) for a complete (full) factorial design with two levels is given by **N= 2^k**, where **k** is the number of variables (factors) in the factorial design at two levels, we will have for the plan k=2 with N=4. To represent these tests, we should symbolize by (-1) the low level of each factor and (+1) the high level. According to the design of experiments method, all testing elements are gathered in matrices of experiment, given below in table (4.3).

Table 4.3: Matrixes of experiment.

N°	V	T	L*	a*	b*	Time
1	-	+	44.04	22.1	16.1	5.731389
2	+	-	43.69	24.91	16.17	9.621354
3	+	+	45.94	23.84	16.34	5.32556
4	-	-	43.86	24.67	15.19	11.15778
Level (-)	1.5 m/s	45 °C				
Level (+)	2.5 m/s	60 °C				

The corresponding response function is a polynomial of the first degree with respect to each of the factors separately, it notes:

$$\mathbf{Y} = \boldsymbol{a_0} + \sum_{\mathbf{i}}^{\mathbf{k}} \mathbf{ai\ Xi} + \sum_{\mathbf{ij}} \mathbf{aij\ Xij} \qquad \textbf{(12)}$$

Where Y is the response predicted by the model, a_0 is the model constant, it answers the average measurement results; Xi is the factor (i); a_i is the effect of factor (i); k is the number of studied factors; a_{ij} is the interaction effect of X_iX_j. According to this reasoning, the equations for the first and second planes can be written, respectively, as:

$$Y=a_0+a_1\ X_1+a_2\ X_2+a_{12}\ X_1\ X_2 \qquad (13)$$

Statistical Analysis

Results were expressed by: Pareto charts to identify the impact of variables on responses, main effect plots, interaction plot and response surface plots to optimize the responses.

4.5.1Effect of Drying Parameters on Drying Time

The values of drying time and redness a* varied between 11.16 and 5.73 hours. Statistical analysis of the experimental design allowed obtaining the figures (4.4. a, b, c, d) and the following model for the drying time:

Drying time = 7,95902 - 0,485564***Velocity** - 2,43055***Temperature** + 0,282648***Velocity***Temperature**

Figures (4.4.a and b) show the effect of drying conditions (A and B) on drying time of tomato paste. The air velocity (A) and drying temperatures (B) have a negative significant effect on drying time with values of 4.86109 and 0.971129, respectively. Figure (4.4.c) presents the effect of the interaction between the drying conditions (AB) on drying time; it is observed that there is a slight negative (AB) effect with a value of 0,565295. Figure (4.4.d) presents the response surface of drying time behavior. It shows that the values of A and B from 57 to 60°C and 1.5 to 2.5m/s respectively, are best in terms of reducing drying time. Which conclude that the drying temperature has the highest effect on drying time compared to air velocity. For that zone, the optimum value of drying time was found to be 5.33 h.

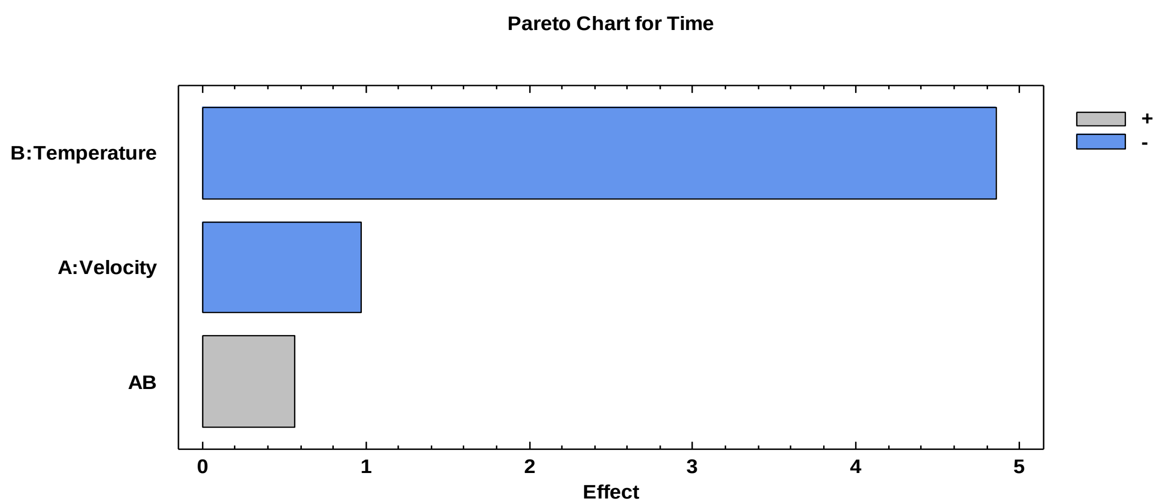


Figure 4.a : Pareto chart for drying time.

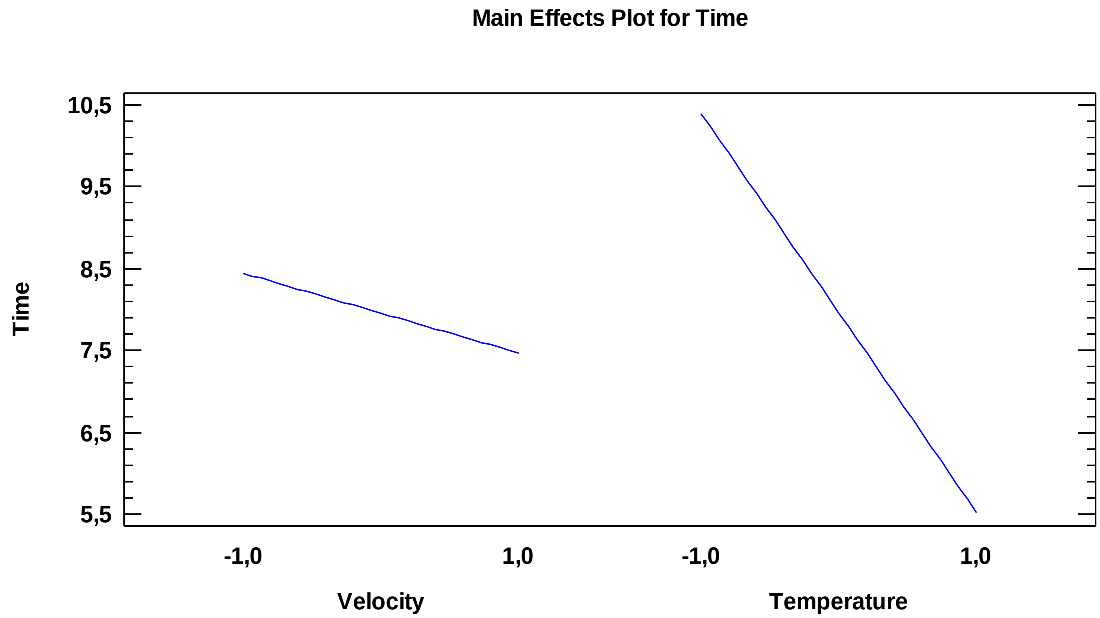


Figure 4.b : Main effects plot for drying time.

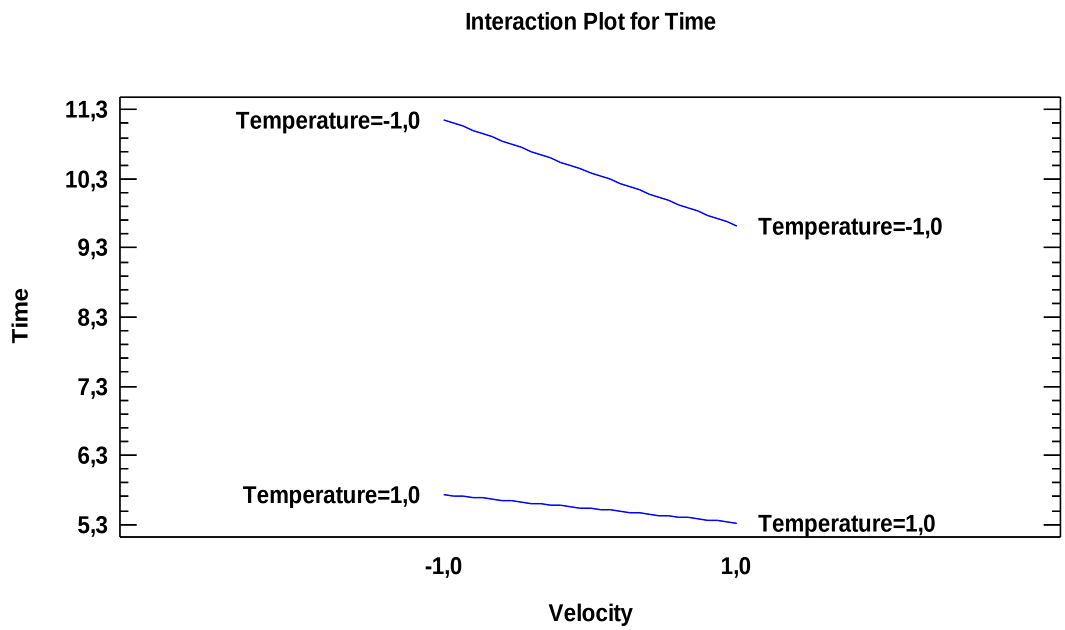


Figure 4.c : Interaction plot for drying time.

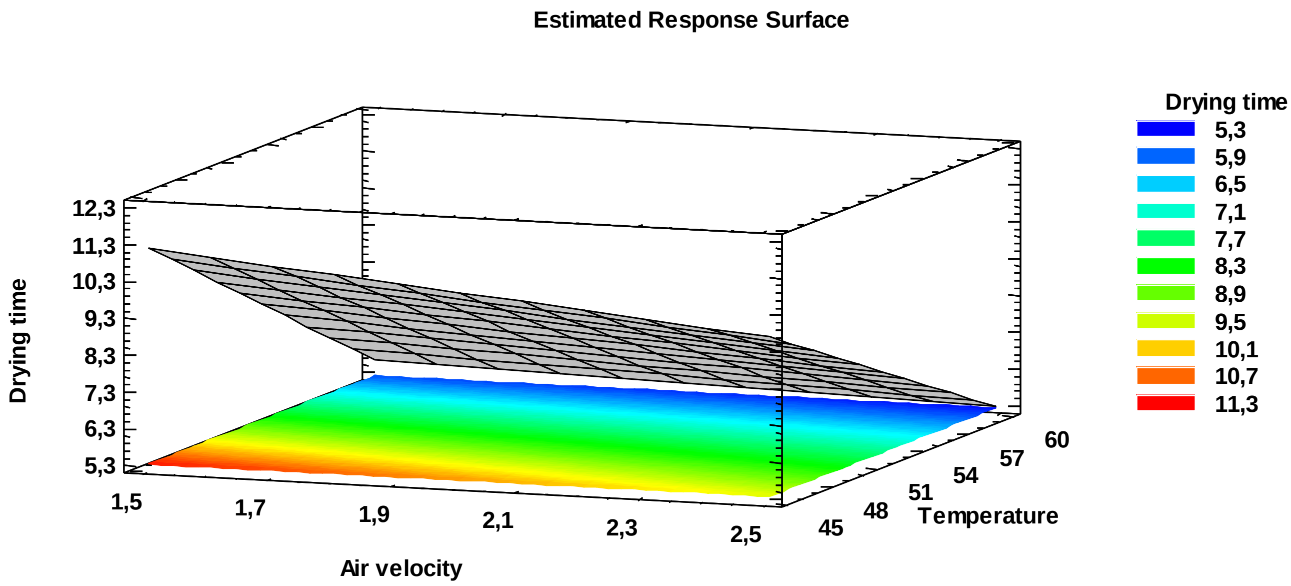


Figure 4.d: Estimated response surface for drying time.

4.5.2 Effect of drying conditions on Color Parameters

The color of the final dried tomatoes may be strongly related to the carotenoid lycopene, which is known to possess enormous health benefits (Rao and Agarwal 1999). This is because lycopene gives the red color of the dried tomatoes. Shi and Lemanguer (2000) have observed that the industrial production of the characteristic red-color-related lycopene from tomatoes is in high demand by the pharmaceutical industries.

For all these parameters above we are focusing on the redness a* of the dried samples, which presents an essential parameter for measuring the quality of dried tomato paste. The values of a* varied between 24.92 and 22.1. Statistical analysis of the experimental design allowed obtaining the figures (4.5.a, b, c, d) and the following model for the color parameter a*:

a* = 23,88 + 0,495***Velocity** - 0,91***Temperature** + 0,375***Velocity***Temperature**

Figures (4.5.a and b) show the effect of drying conditions on color values of a* of dried tomato paste. The drying temperatures have a negative significant effect on a* value with 1.82, and air velocity have a positive effect with 0.99. Otherwise, figure (4.5.c) presents the effect of the interaction between the drying conditions on a* values, it observed a considerable positive interaction effect with a value of

0.75. Figure (4.5.d) presents the response surface of a* values behavior. It observed that the optimum value of a* was found to be 24.91.

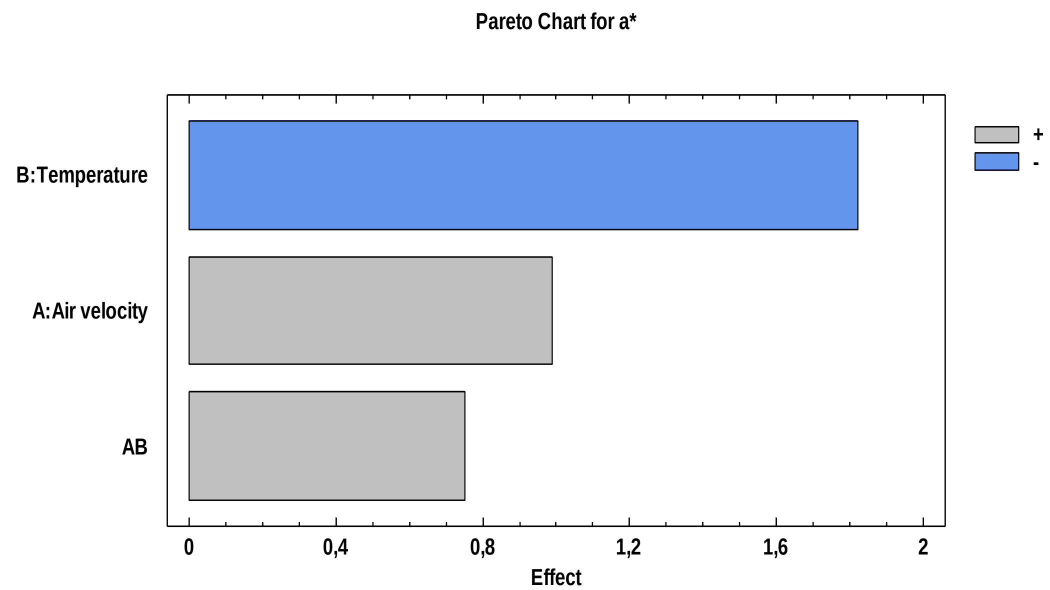


Figure 5.a : Pareto chart for redness a*.

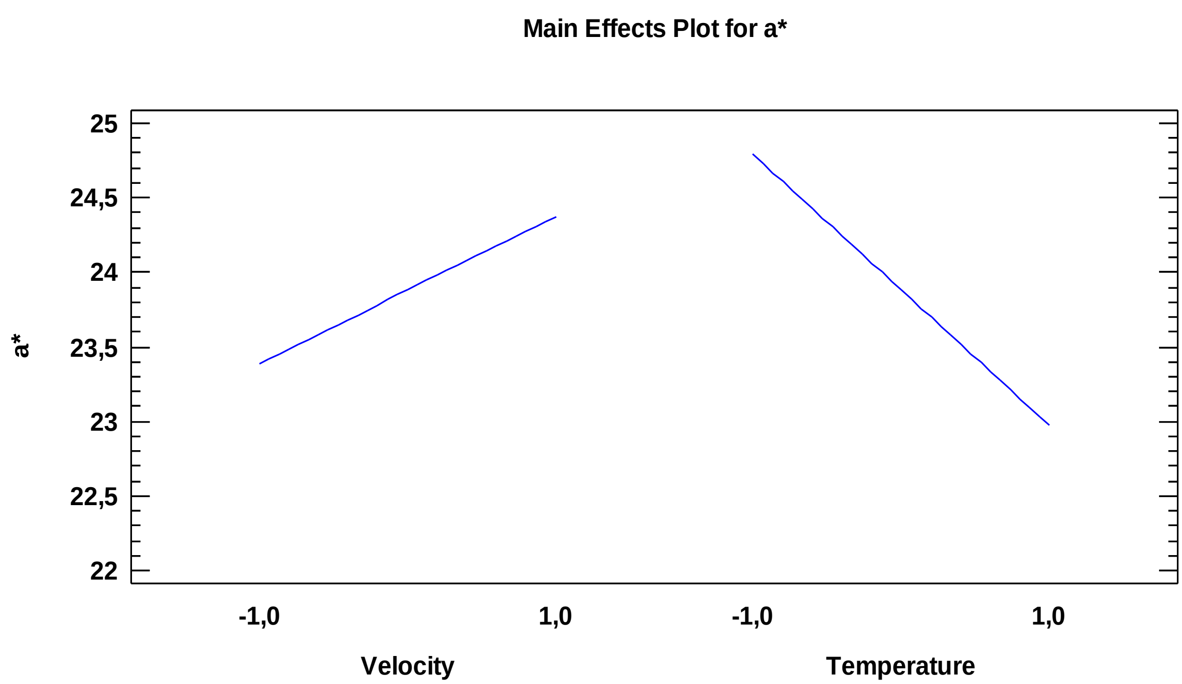


Figure 5.b : Main effects plot for redness a*.

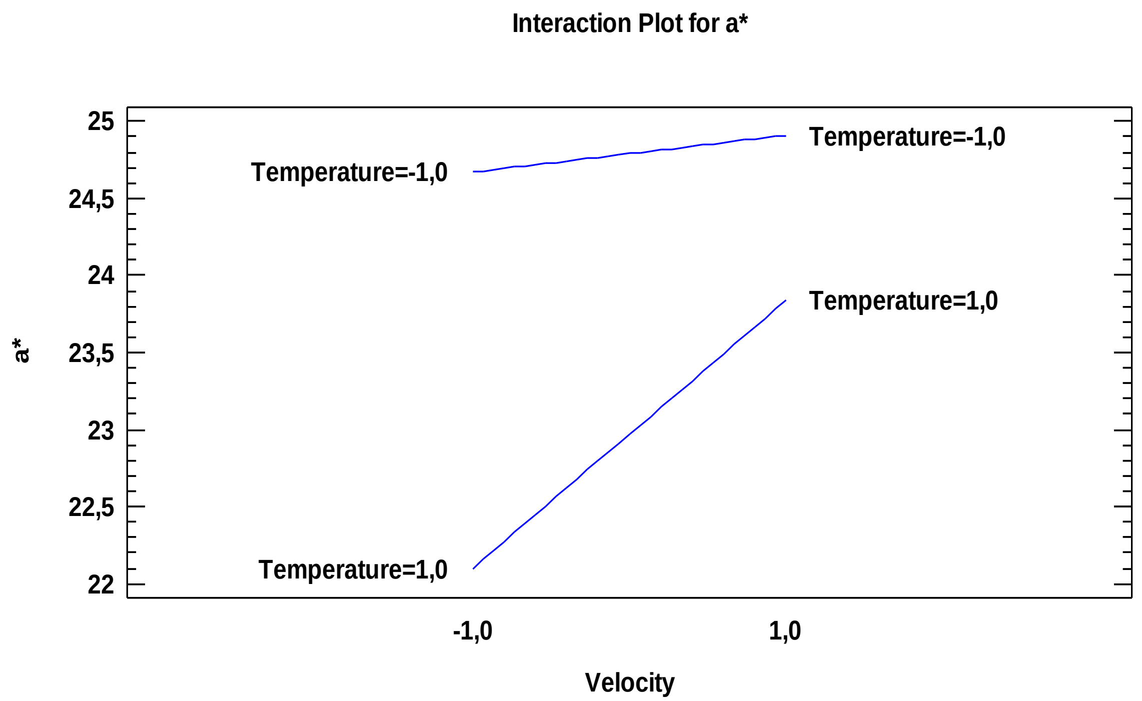


Figure 5.c : Interaction plot for redness a*.

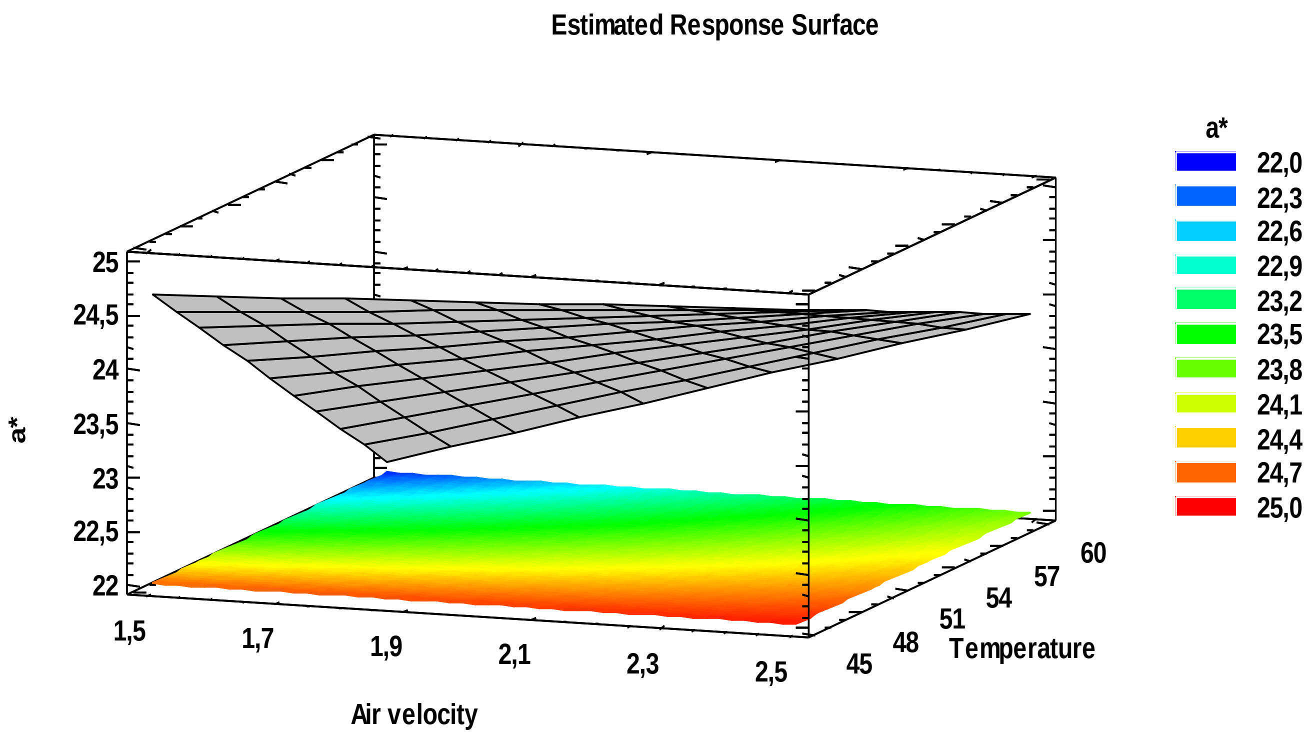


Figure 5.d: Estimated response surface for redness a*.

4.5.3 Optimization of the drying conditions

The desirability of the responses gave an overall desirability of 0.786903. The results predicted with 95% confidence in the range of the studied factors gave optimal drying conditions of 45°C, 2.5 m/s for air temperature, air velocity, respectively. At this optimum condition, the drying time and redness a* were found to be 5.32 hours, 23.84, respectively. The surface plot of the desirability for the optimum parameters is shown in Figure (4.6).

Table 4.4: Factors settings at Optimum.

Factor	Low	High	Optimum
Drying Temperature	-1,0	1,0	0,999998
Velocity	-1,0	1,0	1,0

Table 4.5: Response values at optimum.

Response	Optimum
Drying time	5,32556
a*	23,84

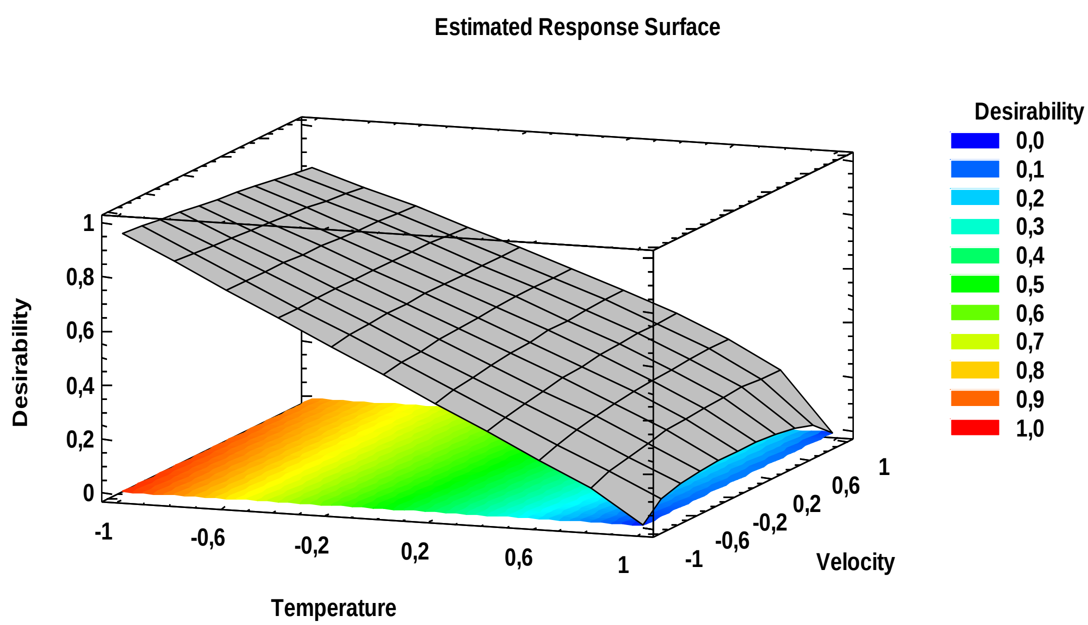


Figure 4.6: The desirability for redness a*.

4.6. Mathematical modeling

Mathematical models that describe drying mechanisms of grain and food provide the required temperature and moisture information. Thin-layer drying models can be categorized as theoretical, semi-theoretical and empirical models. Some semi-theoretical drying models that have been widely used in the literature are presented in form of models, namely, Page, Henderson and Pabis, Two-term, Logarithmic, the simple (Newton), Table (4.6).

Table 4.6: Different mathematical models of drying.

N°	Model	Expression of the model	References
1	Page	$XR(t) = \exp(-k.t^n)$	Diamante and Munro (1993)
2	Henderson and Pabis	$XR(t) = a*\exp(-kt)$	Zhang and Litchfield (1991)
3	Two-term	$XR(t) = a*\exp(-k_0.t) + b\exp(k_1.t)$	Henderson (1974)
4	Logarithmic	$XR(t) = a*\exp(-k.t) + c$	Yagcioglu et al. (1999)
5	Newton	$XR(t) = \exp(-k.t)$	A.Idlimam (2008)

These models are generally derived by simplifying general series solution of Fick's second law. The Page model one of the most commonly used models for explaining the drying kinetics of food materials. It was successfully used to describe drying characteristics of high sugar containing agricultural products such as plum, grape, kiwi and tomato Doymaz I, Pala M (2002). Simal S, Femenia A and al (2005). The moisture ratio (XR) and drying rate of tomato samples during drying experiments were calculated using the following Equation:

$$XR = \frac{X - Xe}{X0 - Xe} \tag{14}$$

Where:

XR: Reduced moisture content.

X: Moisture content, kg water/kg dry matter.

X_0: Initial moisture content, kg water/kg dry matter.

X_{eq}: Equilibrium moisture content, kg water/kg dry matter calculated using the following Equation (15):

$$\frac{Xe}{Xm} = \frac{C.K.HR}{(1 - K.HR).(1 - k.HR + C.K.HR)} \quad (15)$$

With:

$C=1.514.10^{-0.9}. \exp(61089/R.T)$.

$K = 72.765. \exp(-11710/R.T)$.

$X_m = 1.067.10^{-09}. \exp(47614/R.T)$.

Where:

R: Universal constant of perfect gases.

HR: Relative humidity (%).

T: Temperature (°K).

X_m: Monolayer moisture content, kg water/kg dry matter.

To estimate the most appropriate model, the experimental drying curves, as moisture ratio (MR) versus drying time, obtained at different drying temperatures and drying air velocity conditions were fitted to five (5) mathematical models.

The values of the equilibrium moisture content of tomato paste under different drying conditions is calculated and showed in the following table (4.7).

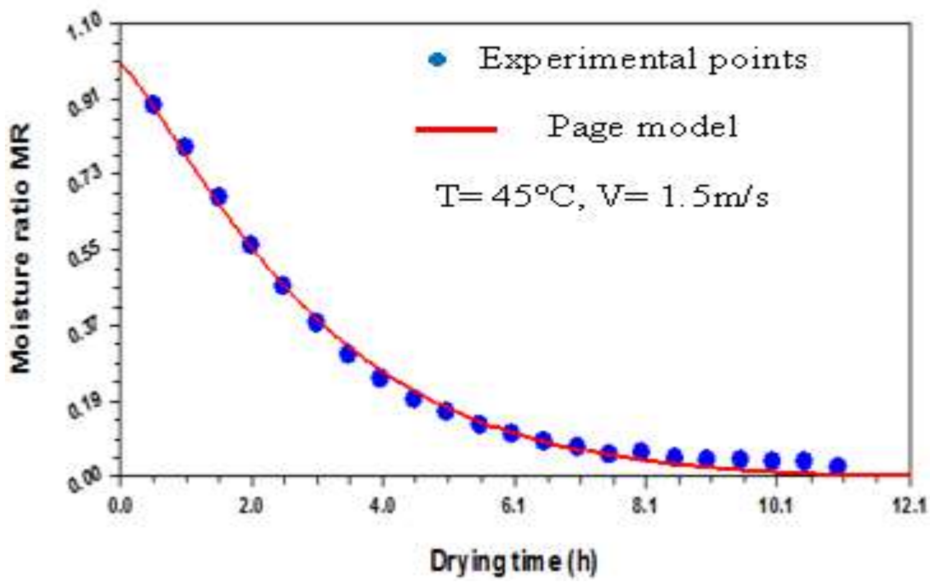
Table 4.7: The equilibrium moisture content values.

T (°C)	T (K)	R	C	K	X_m	RH	X_{eq}
45	318,15	8314	1,5494E-09	72,4435773	1,0864E-09	0,16	1,7393E-19
60	333,15	8314	1,5478E-09	72,4580187	1,0855E-09	0,16	1,7357E-19

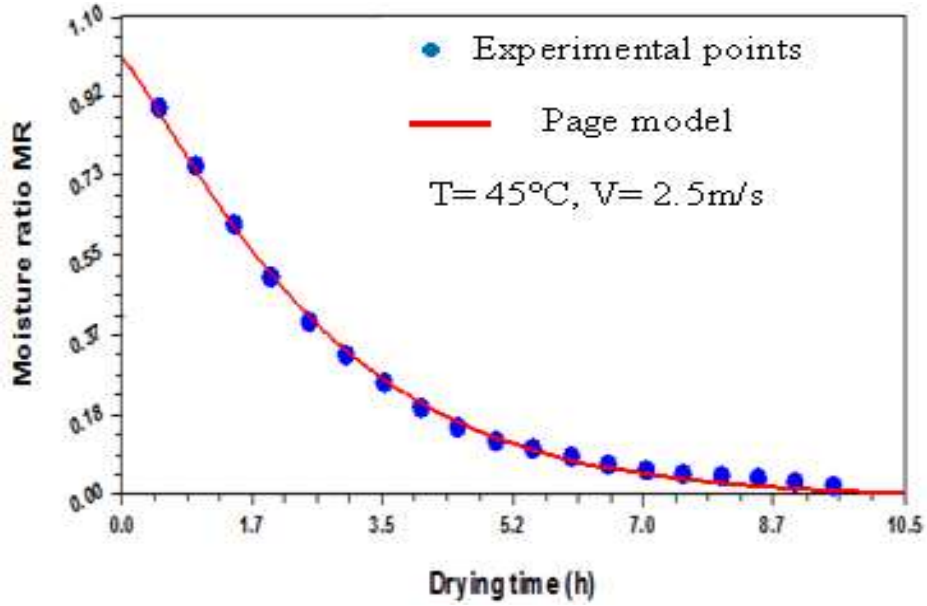
Table 4.8: Statistical results obtained from the selected models.

V (m/s)	T (°C)	Model	Coefficients	S	R
1.5	45	Henderson and pabis	a =1.0674092; k =0.3508736	0.0251532	0.9965834
		Logarithmic	a =1.0720910; k =0.3410238 c =-0.0095472	0.0252676	0.9966961
		Page	k =0.2523305; n =1.2101224	0.0157661	0.9986591
		TwoTerm	a =0.5337061;k_0=0.3504771 b =0.5337064;k_1=0.3512762	0.0262717	0.9965834
		Newton	k =0.3298674	0.0313641	0.9944606
2.5	45	Henderson and pabis	a =1.0574480; k =0.3936647	0.0210645	0.9976536
		Logarithmic	a =1.0668919; k =0.3725490 c =-0.01850007	0.0197447	0.9980370
		Page	k=0.3014804; n=1.1827629	0.0100455	0.9994669
		TowTerm	a =0.5287295;k_0=0.3939162 b =0.5287295;k_1=0.3934332	0.0221454	0.9976536
		Newton	k =0.3735106	0.0266520	0.9960617
1.5	60	Henderson and pabis	a =1.0767857; k =0.5099777	0.0503851	0.9899746
		Logarithmic	a =1.2083146; k =0.3591318 c =-0.16901235	0.0266551	0.9974588
		Page	k =0.3334273; n =1.3945002	0.0080676	0.9997442
		TowTerm	a =0.5384332;k_0 = 0.5106172 b = 0.5384334;k_1= 0.5095415	0.0557029	0.9899746
		Newton	k =0.4765531	0.0560373	0.9864478
2.5	60	Henderson and pabis	a =1.0693175; k =0.5876730	0.0420917	0.9930150
		Logarithmic	a =1.1353476; k =0.4790291 c =-0.0885192	0.0326362	0.9962268
		Page	k =0.4323233; n =1.3291875	0.0106010	0.9995584
		TowTerm	a =0.5346741;k_0=0.5881802 b =0.5346743;k_1=0.5872705	0.0470600	0.9930150
		Newton	k =0.5525038	0.0476575	0.9901360

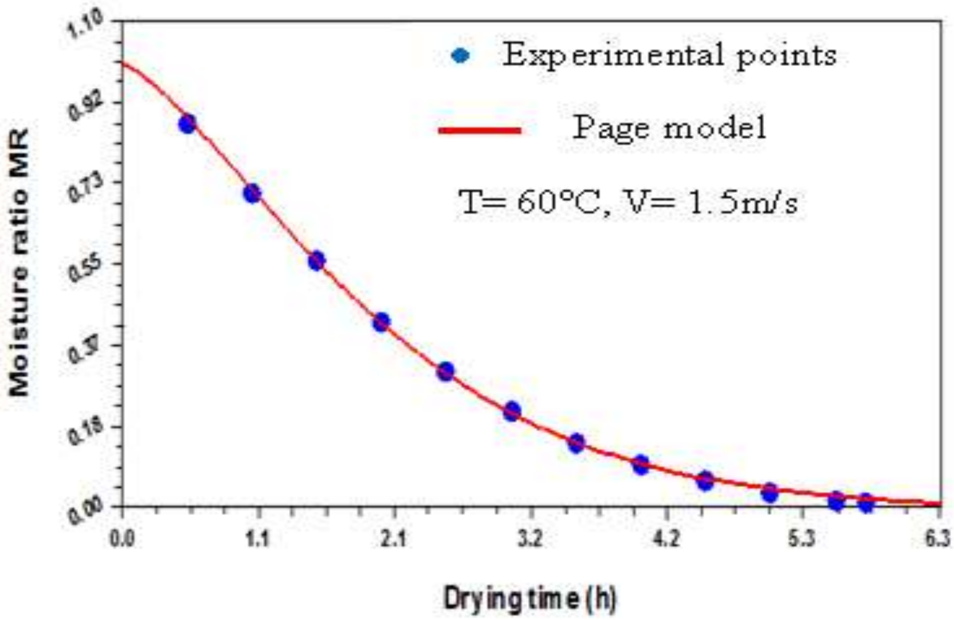
According to the highest values of correlation coefficient r and lowest standard error s on one hand, (r and s =0.9986591; 0.0157661 and0.9994669; 0.0100455) for drying temperature of 45 °C and air-drying velocity of 1.5 and 2.5 m/s; respectively. On the other hand, (r and s =0.9997442; 0.0080676 and 0.9995584; 0.0106010) for drying temperature of 60 °C and air-drying velocity of 1.5 and 2.5 m/s; respectively. Page model, figures (4.7.a, b, c d) was found to be the best-fitted mathematical model to describe tomato paste behavior during the convective drying (Table 4.8). Numerous researches on tomato drying as (Doymaz I (2007)) and (KarelKross R and al (2004)) found that Page model to be the most appropriate in describing the convective drying behavior of respectively fresh tomato halves and osmotically pretreated tomatoes, while (Sacilik and al (2006)) considered the approximation of diffusion model in representing solar tunnel drying behavior of organic tomato.



Figures 7.a: Experimental moisture ratio and stimulated by Page model at T=45°C, V=1.5 m/s.



Figures 7.b: Experimental moisture ratio and stimulated by Page model at T=45°C, V=2.5 m/s.



Figures 7.c: Experimental moisture ratio and stimulated by Page model at T=60 °C, V=1.5 m/s.

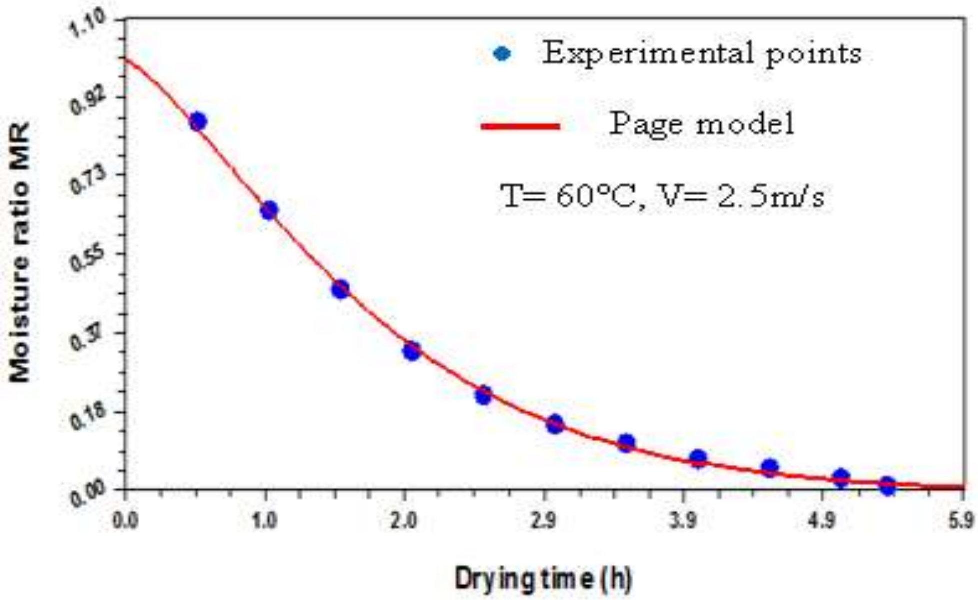
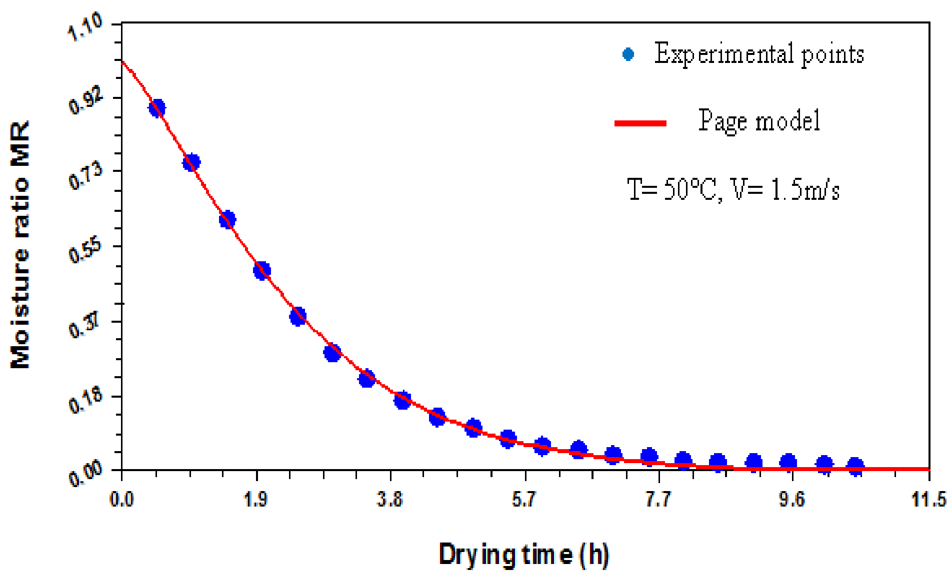


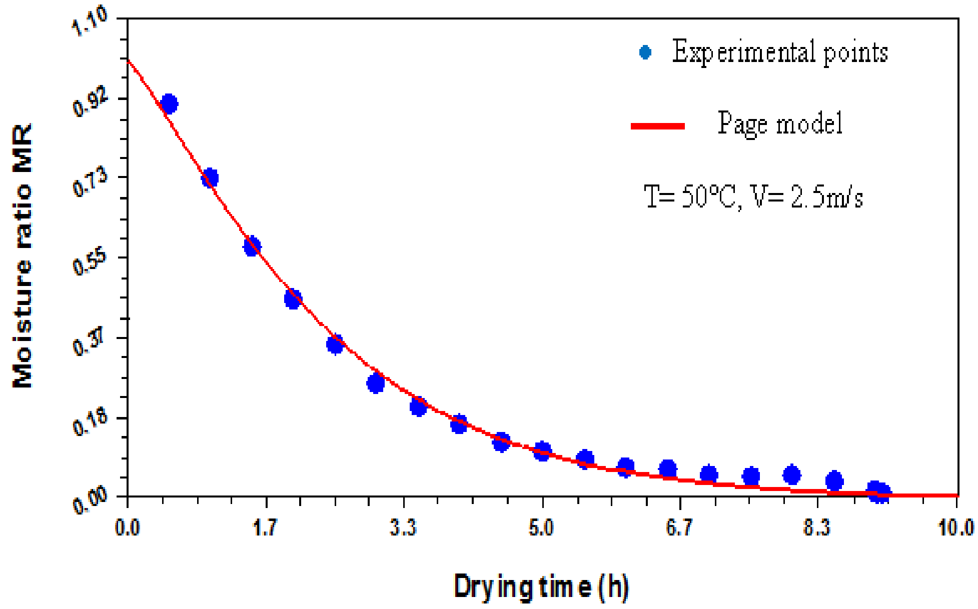
Figure 7.d: Experimental moisture ratio and stimulated by Page model at T=60 °C, V=2.5 m/s.

4.7 Validation of the model

The results are obtained for a drying air temperature of 50°C and two levels air velocity of 1.5m/s and 2.5m/s. Figures (4.8. a and b) represent the experimental and simulated evolutions of the average water content. We can remark that the two profiles have the same trend and there is a satisfactory agreement between experimental and simulation results.



Figures 8.a: Experimental moisture ratio and stimulated by Page model at T=50 °C, V=1.5 m/s.



Figures 8.b: Experimental moisture ratio and stimulated by Page model T=50 °C, V=2.5 m/s.

Conclusion

Conclusion

This study was carried out with the objective of valorize the surplus of the local tomato production using convective drying methods. The tomato paste in the form of ortanique matter was invested

Thus, after having developed a method for preparing tomato paste while preserving another valuable by-product, tomato juice; this work focused on experiments, optimization, and modeling of tomato paste drying.

The effects of two drying parameters (air temperature, air velocity) on drying time and color quality of dried tomato paste were investigated. The drying kinetics of tomato paste were then established using an automated laboratory drying loop (LETTM, El-Manar University of Tunis). they were conducted under air conditions as constant relative humidity of 16%, temperatures 45°C, 50°C, 60°C with airflow velocity of 1.5 and 2.5m/s. Obtained drying kinetics showed only falling periods and led to drying time ranged between 11.16 and 5.32 hours.

A 2^2 complete factorial experimental design was used to investigate the effects of drying parameters on drying time and red color a* quality. Second-order empirical models, response surface plots, main effect plots, interaction plots and Pareto charts were generated. Within the temperature range investigated, the main effects of increasing air temperature significantly decreased the drying time and the red color quality a*. On the other hand, an increase in air velocity increased the redness a* values but increased the drying time significantly. The prediction of the desirability model gave optimal drying conditions of 45°C, 2.5 m/s for air temperature and air velocity, respectively.

In the last part of the study, we've evaluated the suitability of a set of mathematical models, describing thin-layer drying behavior of tomato paste. We found that Page Model was the best fitted among five investigated models. In addition, it can be accepted as an alternative empirical model in order to describe drying behavior of tomato paste in the studied convective and vertical downward flow dryer.

References

Ahmad Fudholi, KamaruzzamanSopian, Mohammad H. Yazdi, MohdHafidzRuslan, Mohamed Gabbasa, Hussein A. Kazem, Performance analysis of solar drying system for red chili, Solar Energy, 99: 47–54, 2014.

Alberto-JesúsPerea-Moreno, Adel Juaidi, Francisco Manzano-Agugliaro, Solar greenhouse dryer system for wood chips improvement as biofuel, Journal of Cleaner Production, 135: 1233 - 1241, 2016.

A.R. Celma, F. Cuadros and F. López-Rodriguez, 'Characterisation of Industrial Tomato By- Products from Infrared Drying Process', Food and Bioproducts Processing, Vol. 87, N°4, pp.282 – 291, 2009.

ARSLAN, D. and ÖZCAN, M.M. Evaluation of drying methods with respect to drying kinetics, mineral content, and colour characteristics of rosemary leaves. Energy Convers. Manage. 49(5), 1258–1264. 2008.

Blaise KamenanKoua, Paul MagloireEkounKoffi, Prosper Gbaha, Evolution of shrinkage, real density, porosity, heat and mass transfer coefficients during indirect solar drying of cocoa beans, Journal of the Saudi Society of Agricultural Sciences, xxx: xxx–xxx. Article in press, 2017.

cuisinés I. Doymaz, 'Air-Drying Characteristics of Tomatoes', Journal of Food Engineering, Vol. 78, N°4, pp. 1291 - 1297, 2007.

Davies, J.N., & Hobson, G.E, The constituents of tomato fruit- the influence of environment, nutrition, and genotype. Critical Reviews in food science and nutrition, 15(3), 205, 280, (1981).

D. Bechkia Crop drying by indirect active hybrid solar – Electrical dryer in the eastern Algerian Septentrional Sahara. Solar Energy 83 (2009) 2223–2232. (2009).

D. Mennouche*, A. Khenblouche, A. Boubekri, B. Bouchekima, S. Boughali, M.Lati, Etude expérimental d'un nouveau procédé de séchage solaire destiné pour le séchage de la pâte de tomate, Vol.5 pp.22-27 ,2017.

Doymaz I, Air-drying characteristics of tomatoes. J Food Eng 78:1291–1297. (2007).

Doymaz I, Pala M The effects of dipping pretreatments on air-drying rates of the seedless grapes. J Food Eng 52:413–417. (2002).

Doymaz I, The kinetics of forced convective air-drying of pumpkin slices. J Food Eng 79:243–248. (2007).

Drouzas, A.E., Tsami, E., Saravacos, G.D, Microwave vacuum drying of model fruit gels. Journal of Food Engineering 39 (2), 117–122. 1999.

Goupy, Jacques. Pratiquer les plans d'expériences. Coll. « Technique et ingénierie.Série conception ». Paris:Dunod, xvi, 551 p. p. 2005.

KarelKross R, Moreira Cavalcanti Mata MER, Martins Duarte ME, Junior VS Drying kinetics of tomatoes (LycopersiconesculentumL.) submitted to a previous osmotic treatment. In: Proceedings of the 14th international drying symposium (IDS 2004). vol. C, pp 2133–2140.

KisselminaKone. Amélioration de la qualité de la tomate séchée par microondes assistés par air chaud avec pilotage de la puissance spécifique. Food engineering. AgroParisTech; INP-HB, 2011.

Lin, M.L., Durance, T.D., Scaman, H.S., Characterization of vacuum microwave air and freeze-dried carrot slices. Journal of Food Research International 31 (2), 111–117. 1998.

Markovic, K., Hruskar, M., &Vahcic, N, Lycopene content of tomato products and their contribution to the lycopene intake of Croatians. Nutrition Research, 26(11), 556-560, (2006).

Maritza Alonzo Macias. Comparatives studies of deferent drying process of strawberry hot air-drying freeze-drying and swell drying: application on the biological compounds preservation. Other. Université de La Rochelle, 2013. English.

RAO, A.V. and AGARWAL, S. Role of lycopene as antioxidant carotenoid in the prevention of chronic diseases: A review. Nutr. Res. 19(2), 305–323. 1999.

Sacilik et al, Mathematical modeling of solar tunnel drying of thin layer organic tomato. J Food Eng 73:231–238. (2006).

S. Boughali, H. Benmoussa and al, Crop drying by indirect active hybrid solar – Electrical dryer

in the eastern Algerian Septentrional Sahara; Solar Energy 2223–2232. (2009).

SHI, J.X. and LEMANGUER, M. Lycopene in tomatoes. Chemical and physical properties affected by processing. Crit. Rev. Food Sci. Nutr. 40(1), 1–42. 2000.

Simal S, Femenia A, Garau MC, Rossello C Use of exponential, page’s and diffusional models to simulate the drying kinetics of kiwi fruit. J Food Eng 66:323–328. (2005).

Wu, Chien-Fu, et Michael Hamada. Experiments: planning, analysis, and optimization, 2nd. Hoboken, N.J.: Wiley, 716 p. 2009.

Zanoni, B., Peri, C., Nani, R., Lavelli, V., Oxidative heat damage of tomato halves as affected by drying. Journal of Food Research International 31 (5), 395–401. 1998.

Annex

Annex

1. Effect of Drying Parameters on Color Parameters L*, b*

1.1 Brightness (L*)

Statistical analysis of the experimental design allowed obtaining the following model for the Brightness L*:

$$L^* = 44.3825 + 0.4325*Velocity + 0.6075*Temperature + 0.5175*Velocity*Temperature$$

Tab 01: Regression coefficients for L*.

Estimate	Coefficient
44.3825	constant
0.4325	A:Velocity
0.6075	B:Temperature
0.5175	AB

Figure (1.a and b) show the effect of drying conditions on color values of L* of dried tomato paste. The drying temperatures and air velocity have a positive significant effect on L* with values of 1,215and 0,865 respectively. Otherwise, figure (1.c) presents the effect of the interaction between the drying conditions on color values of L*, we observed that the increasing of drying air velocity with increasing in drying temperature increase the color values of L*, where the best interaction effect is recorded for T=60°C and V=2.5 m/s with an optimum value of 1,035. Figure (1.d) presents the response surface of color values of L* behavior. we noted that the values of drying temperature and air drying velocity varied between 56 to 60°C and 2.3 to 2.5 m/s, respectively, for the optimal L* value of 45.94.

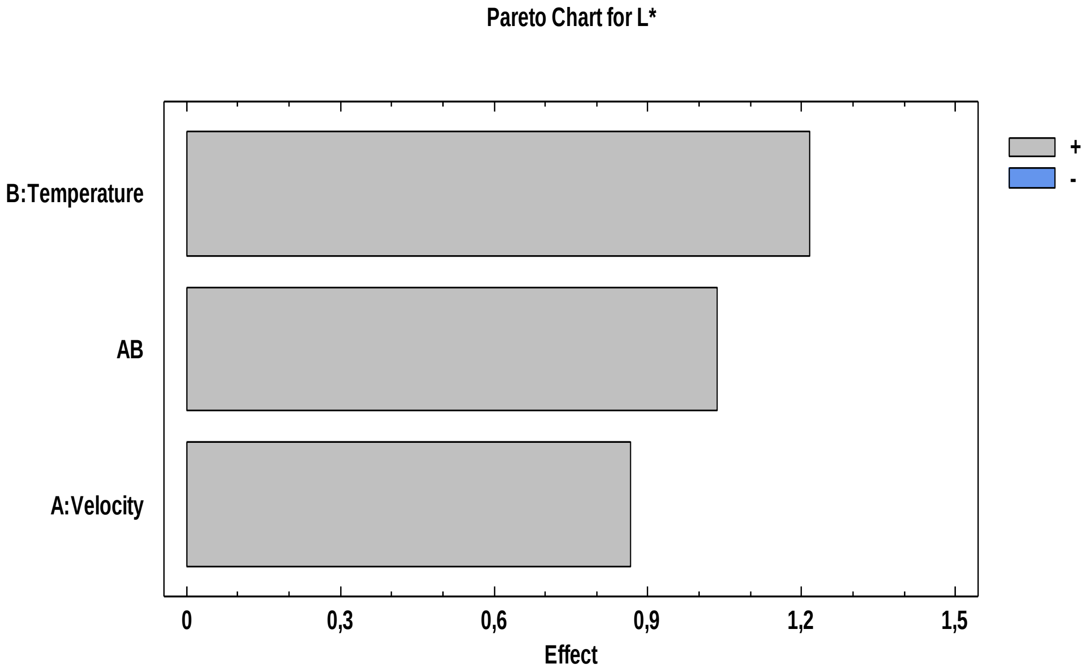


Figure 1.a : Pareto chart for brightness L*.

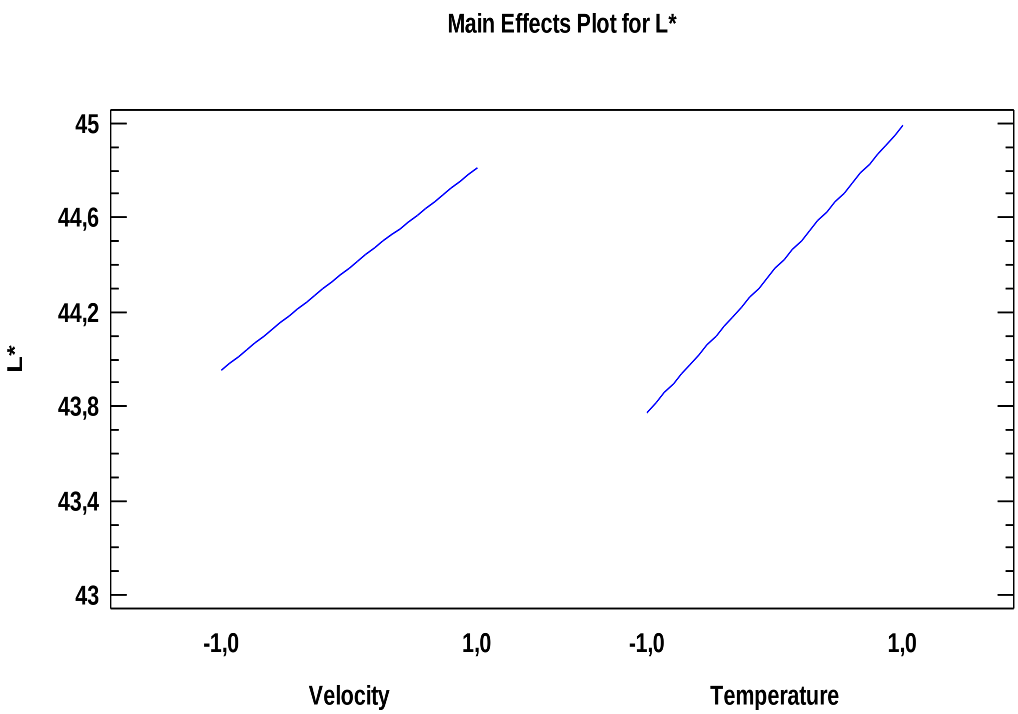


Figure 1.b : Main effects plot for brightness L*.

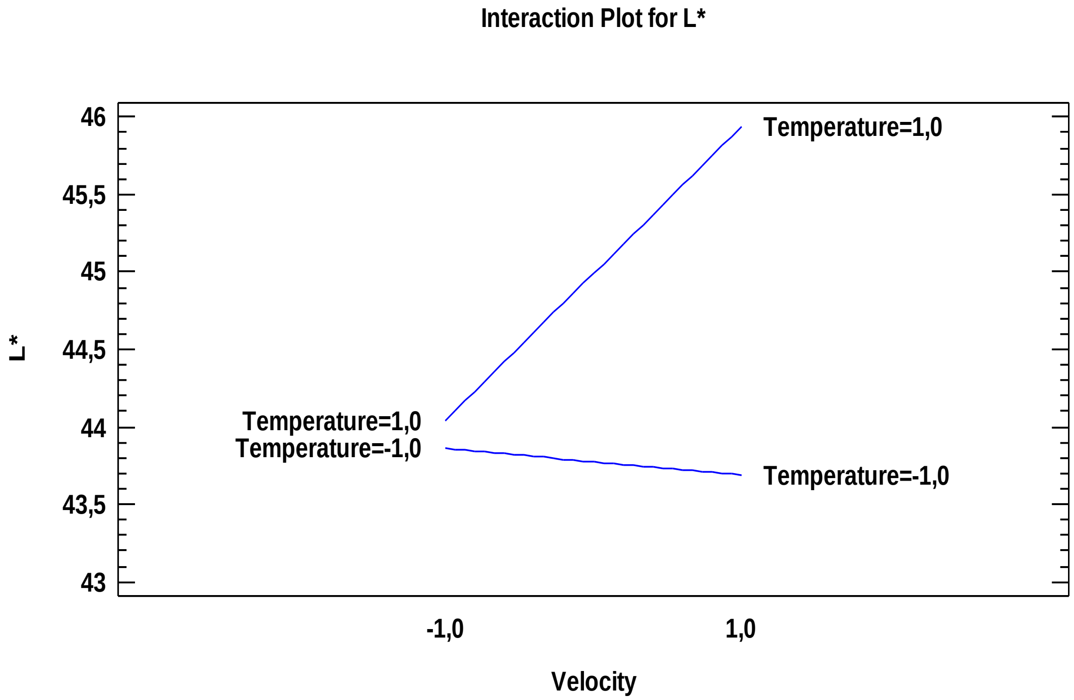


Figure 1.c : Interaction plot for brightness L*.

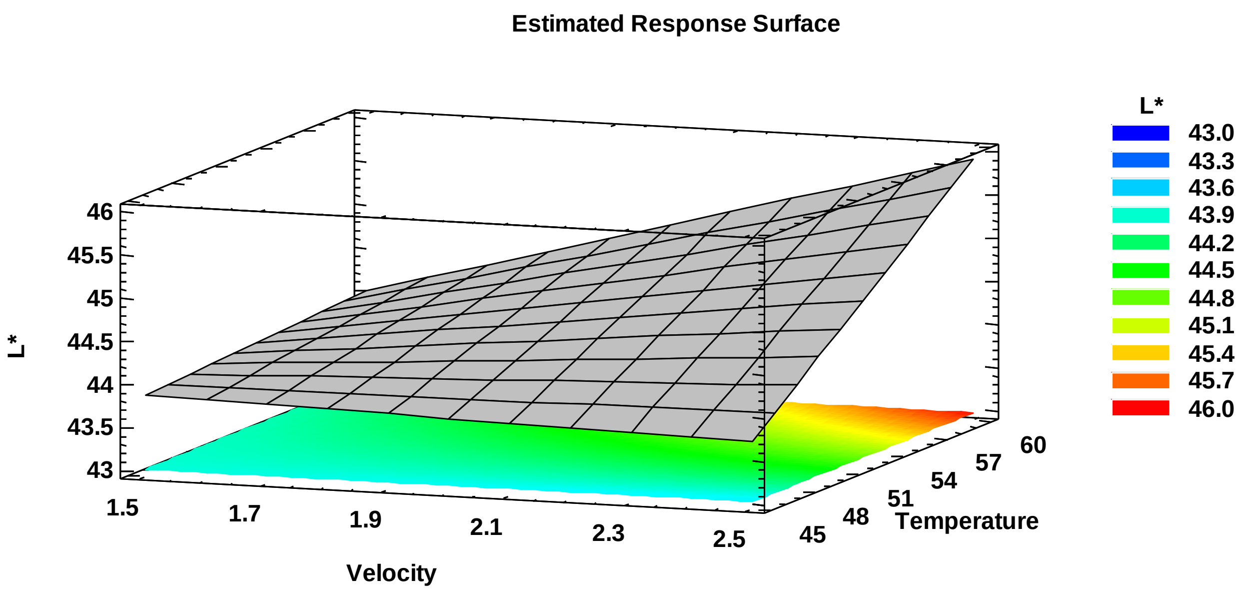


Figure 1.d: Estimated response surface for brightness L*.

1.2 Yellow–blue axis (b*)

Statistical analysis of the experimental design allowed obtaining the following model for the Yellow–blue axis b*:

b* = 15.95 + 0.305*Velocity + 0.27*Temperature - 0.185*Velocity*Temperature

Tab 02: Regression coefficients for b*.

Estimate	Coefficient
15.95	constant
0.305	A:Velocity
0.27	B:Temperature
-0.185	AB

Figure (2.a and b) show the effect of drying conditions on color values of b* of dried tomato paste. The (B) and (A) have a positive significant effect on b* values with values of 0.54 and 0.21, respectively, with a negative interaction (AB) between (A) and (B). Figure (2.c) presents the effect of (AB) on color values of b*, we observed a considerable negative (AB) effect, where the best (AB) effect is recorded for T=45°C and V=1.5 m/s with an optimum value of 0.37. Figure (2.d) presents the response surface of color values of b*, It shown that the values of (A) and (B) varied between 1.5 to 1.7 m/sand 45 to47°C, respectively for the optimal b* value 15.19.

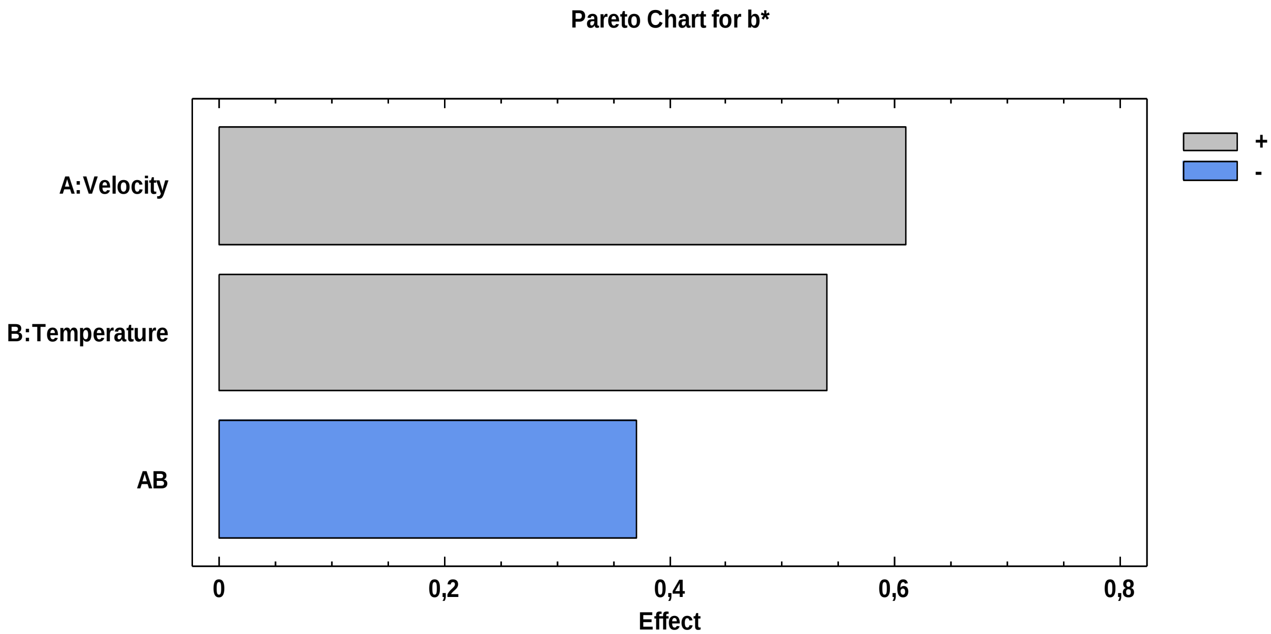


Figure 2.a : Pareto chart for yellowness b*.

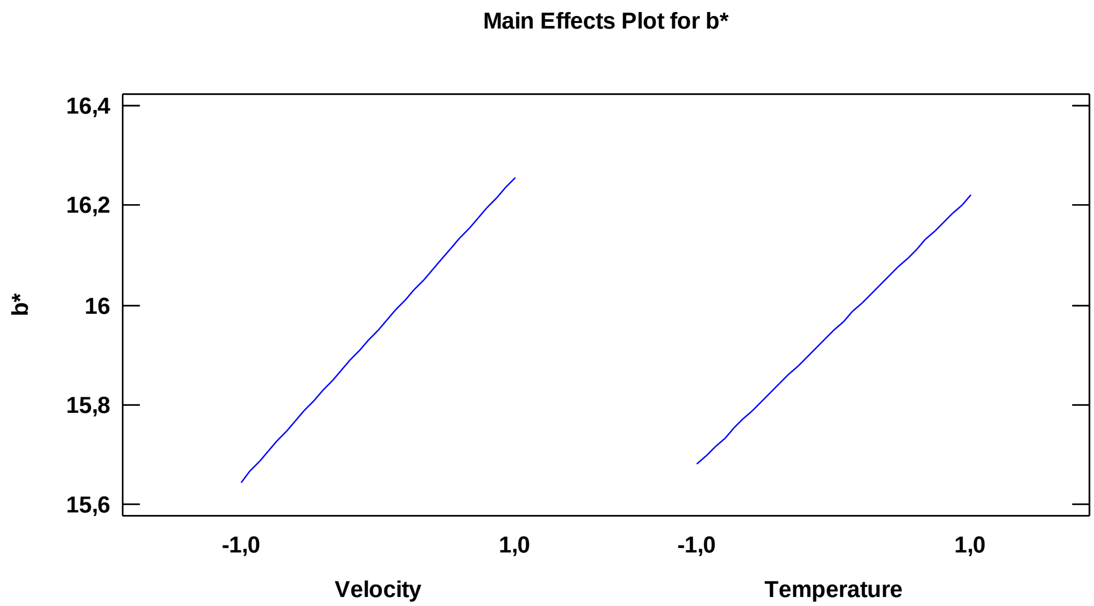


Figure 2.b : Main effects plot for yellowness b*.

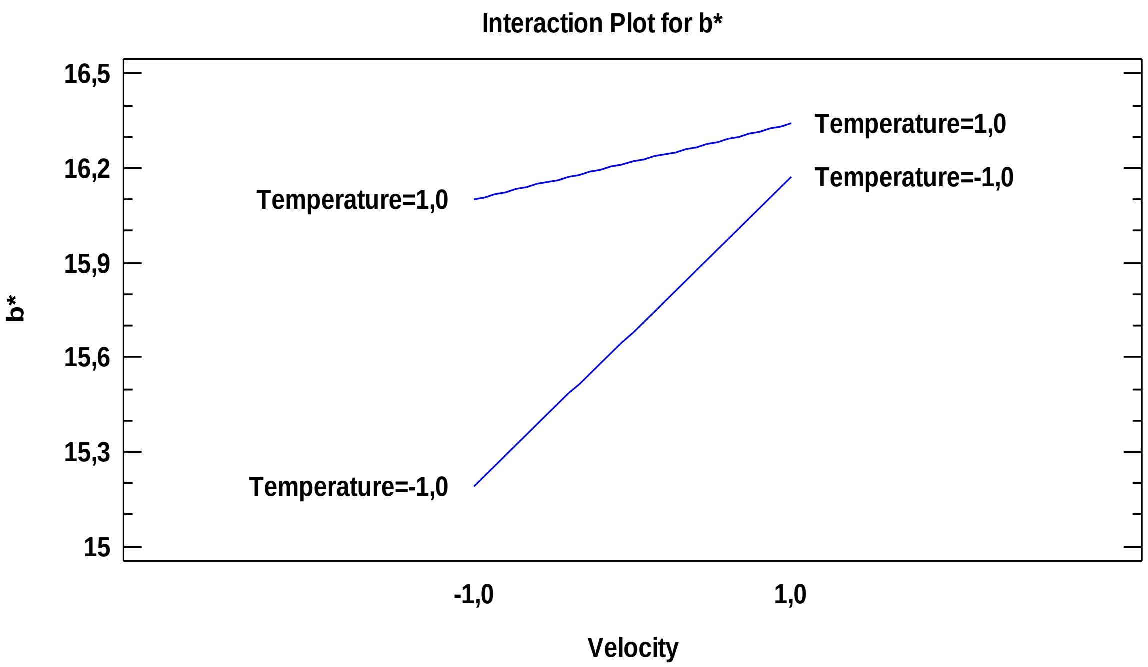


Figure 2.c : Interaction plot for yellowness b*.

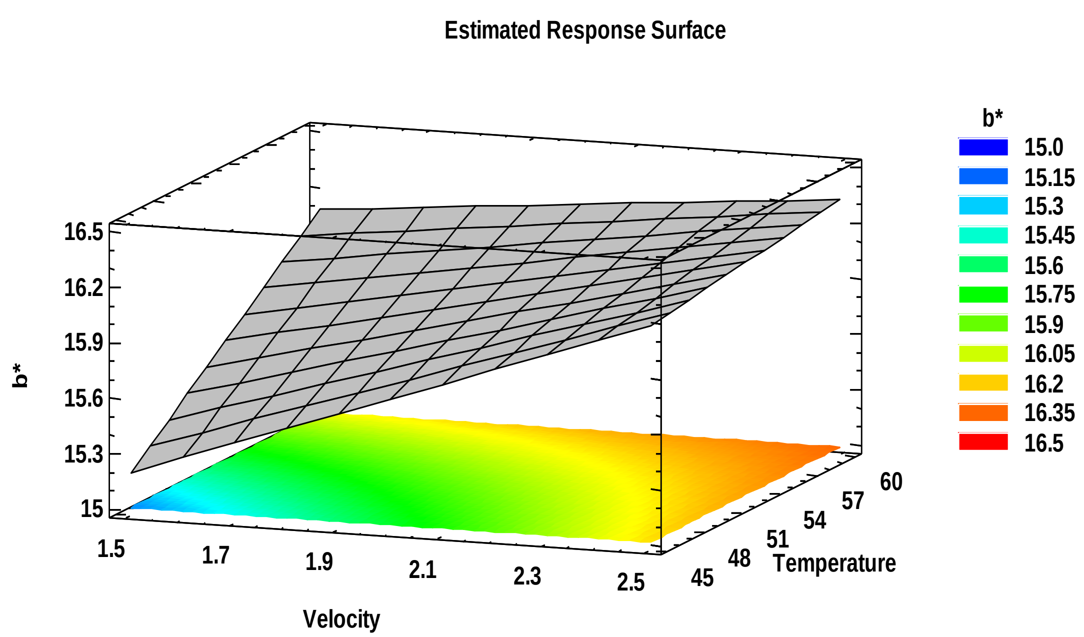
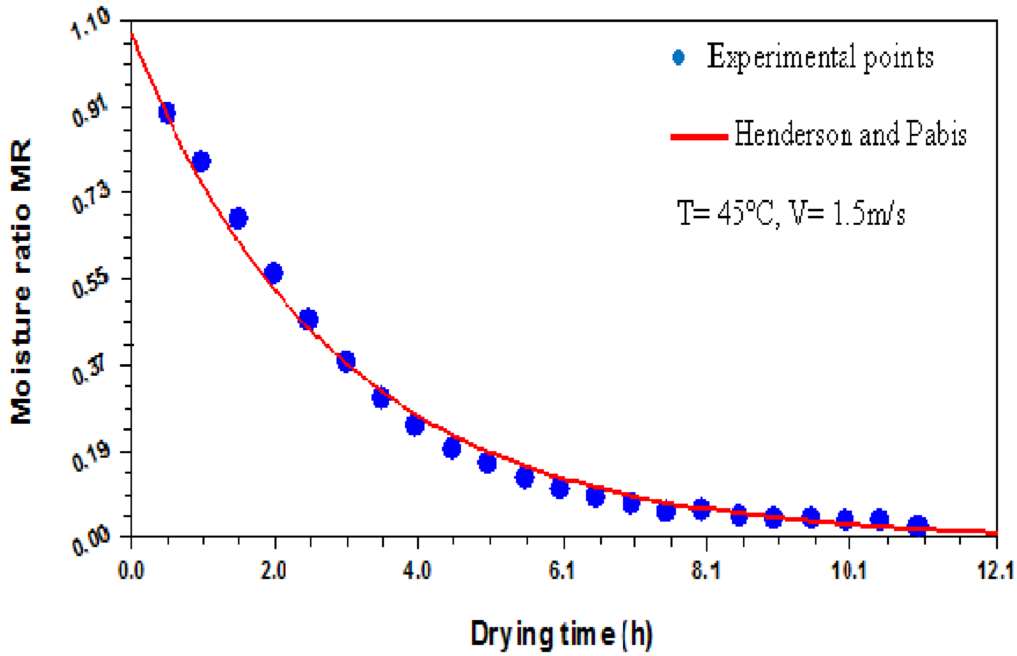
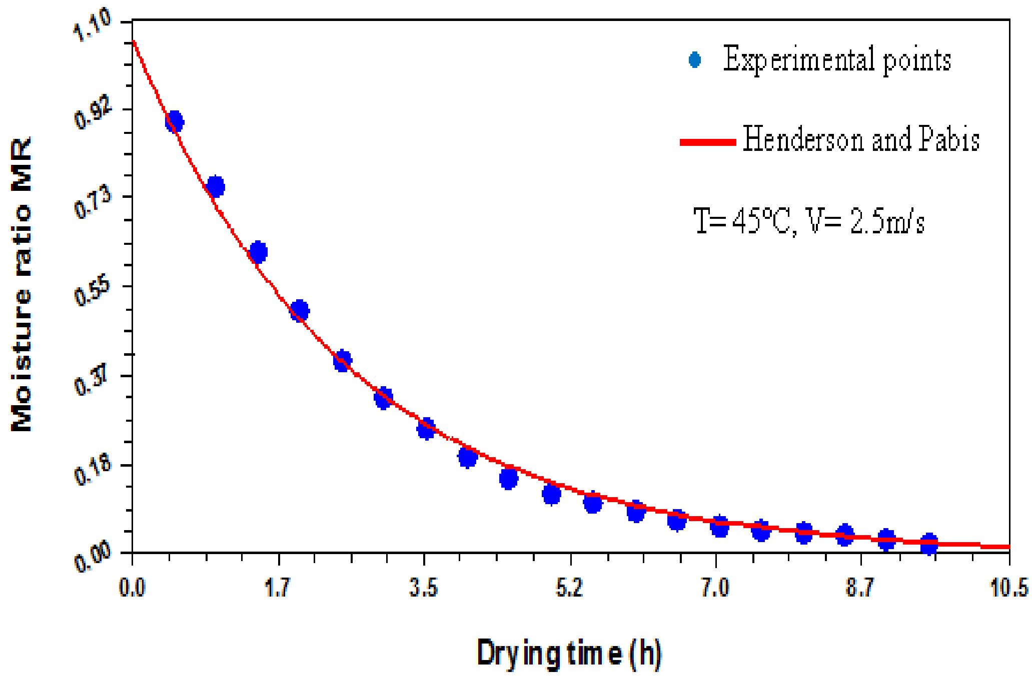


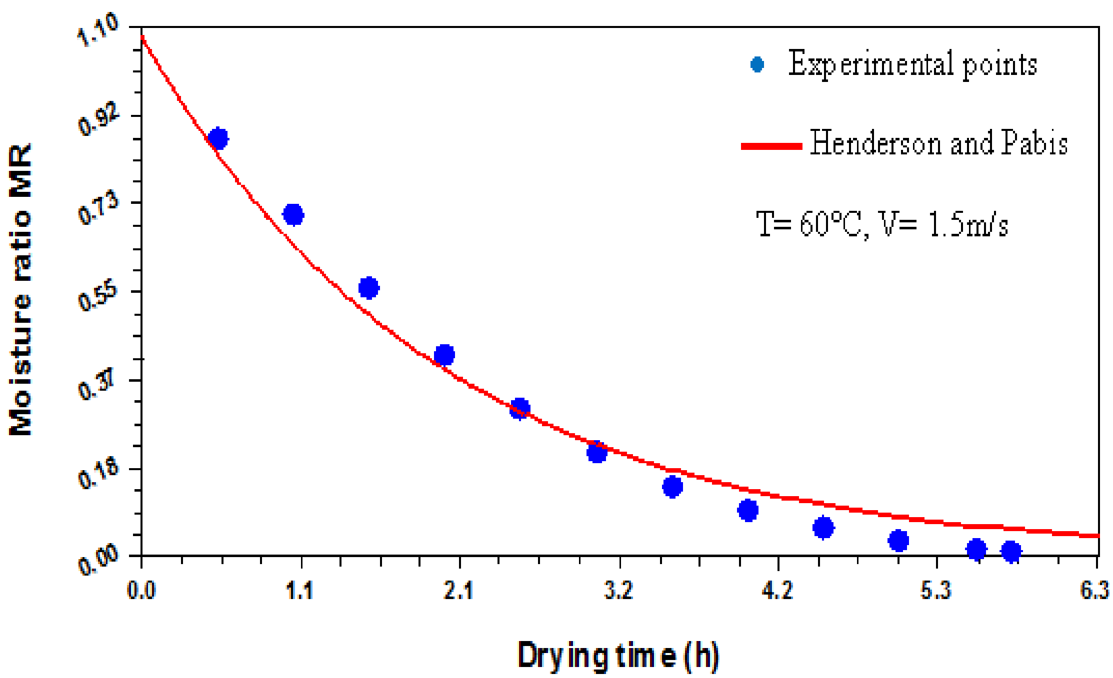
Figure 2.d: Estimated response surface for yellowness b*.

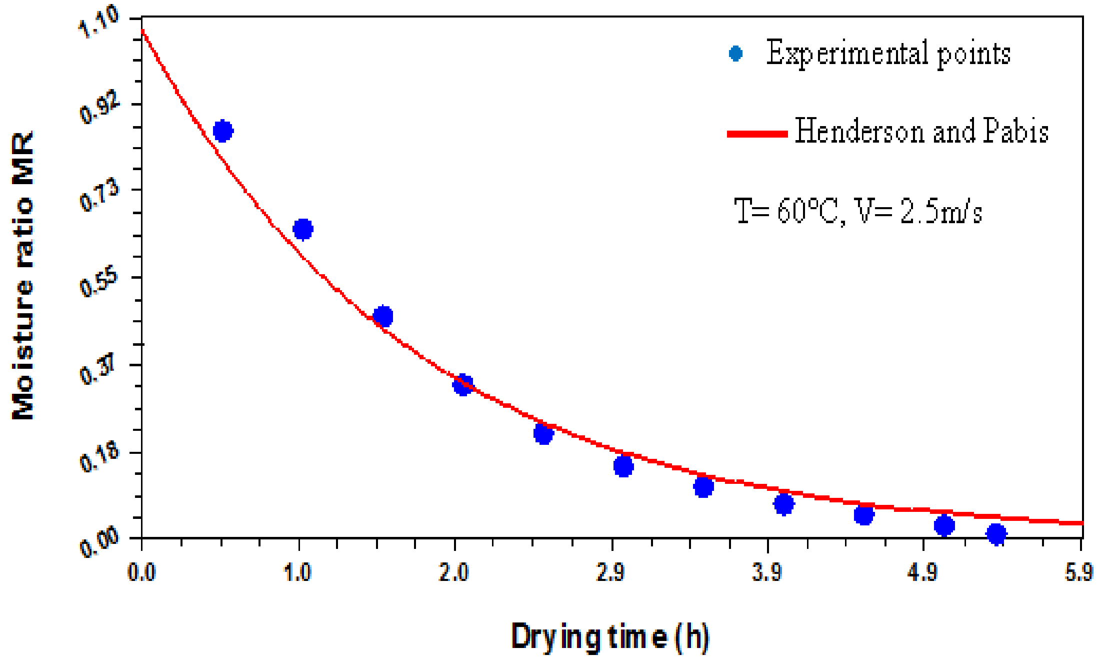
2. Representative figures of the experimental drying curves by the different models selected

2.1. Henderson and Pabis model

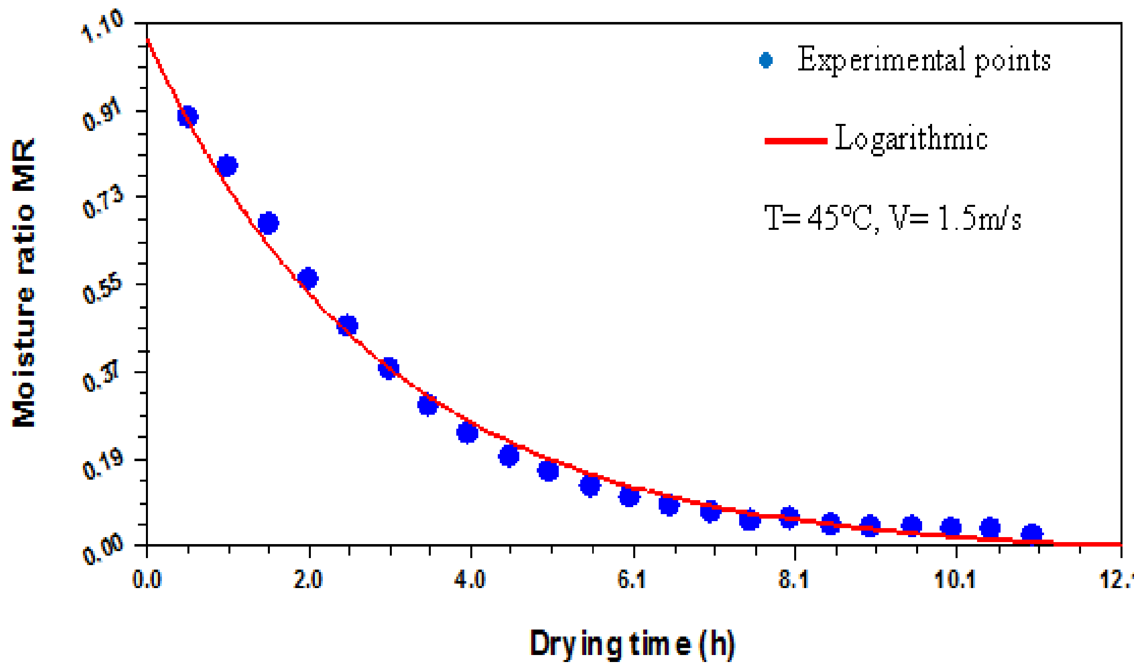


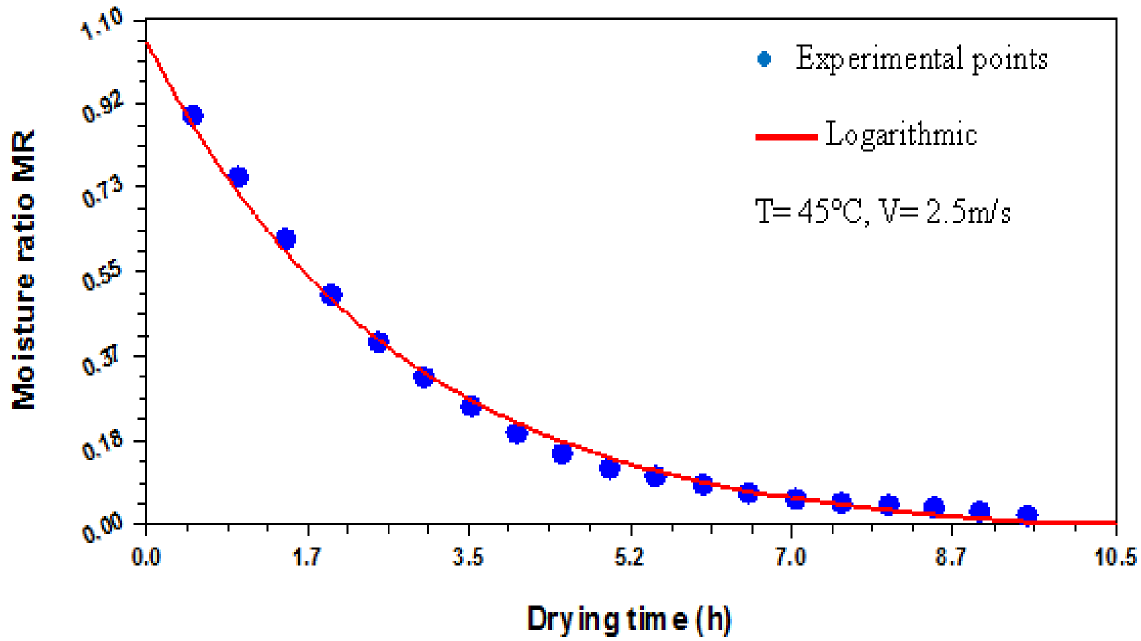

Experimental points
Henderson and Pabis
T= 45°C, V= 2.5m/s
Moisture ratio MR
Drying time (h)
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.7
3.5
5.2
7.0
8.7
10.5

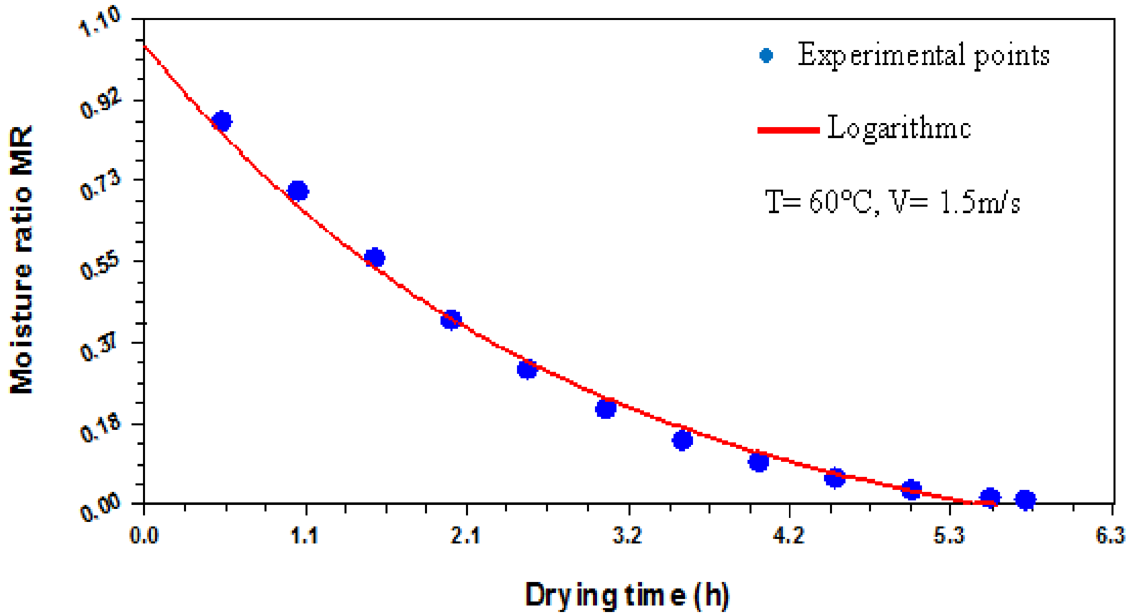

Experimental points
Henderson and Pabis
T= 60°C, V= 1.5m/s
Moisture ratio MR
Drying time (h)
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.1
2.1
3.2
4.2
5.3
6.3

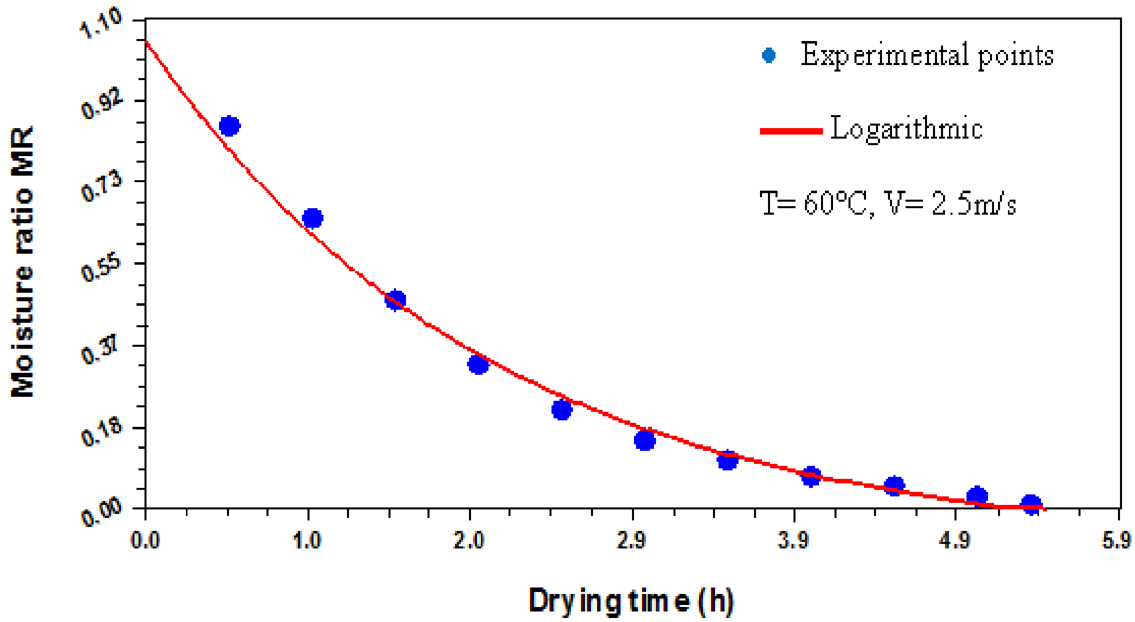


2.2. Logarithmic model

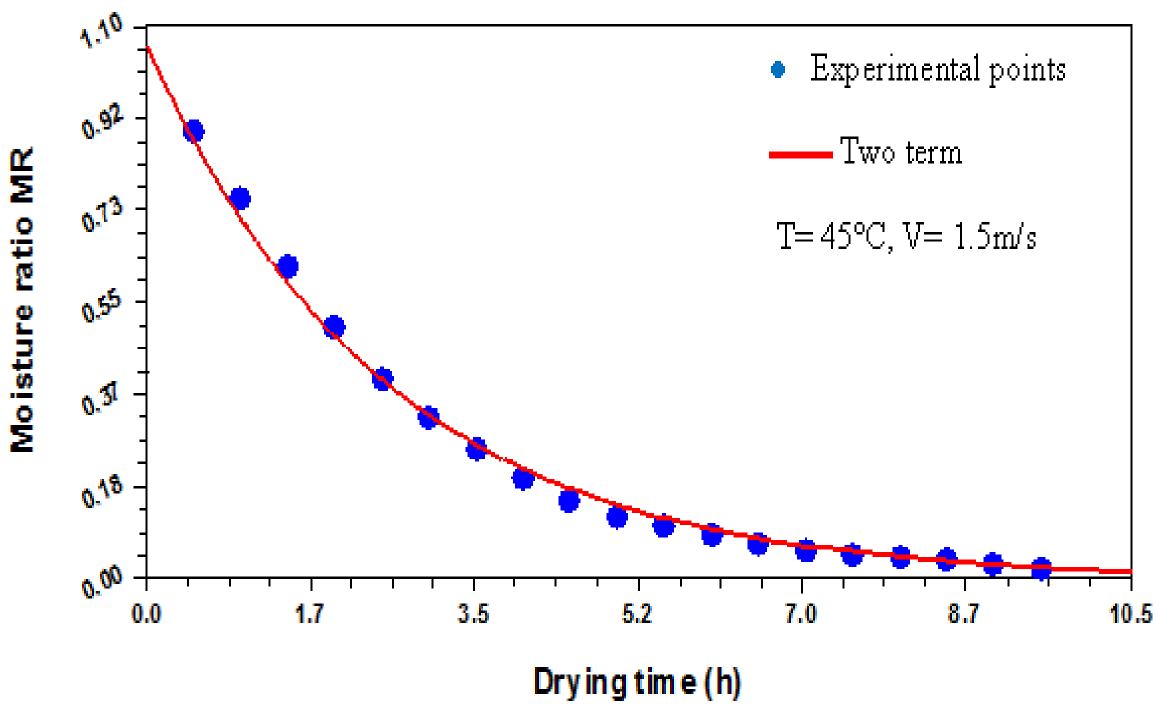


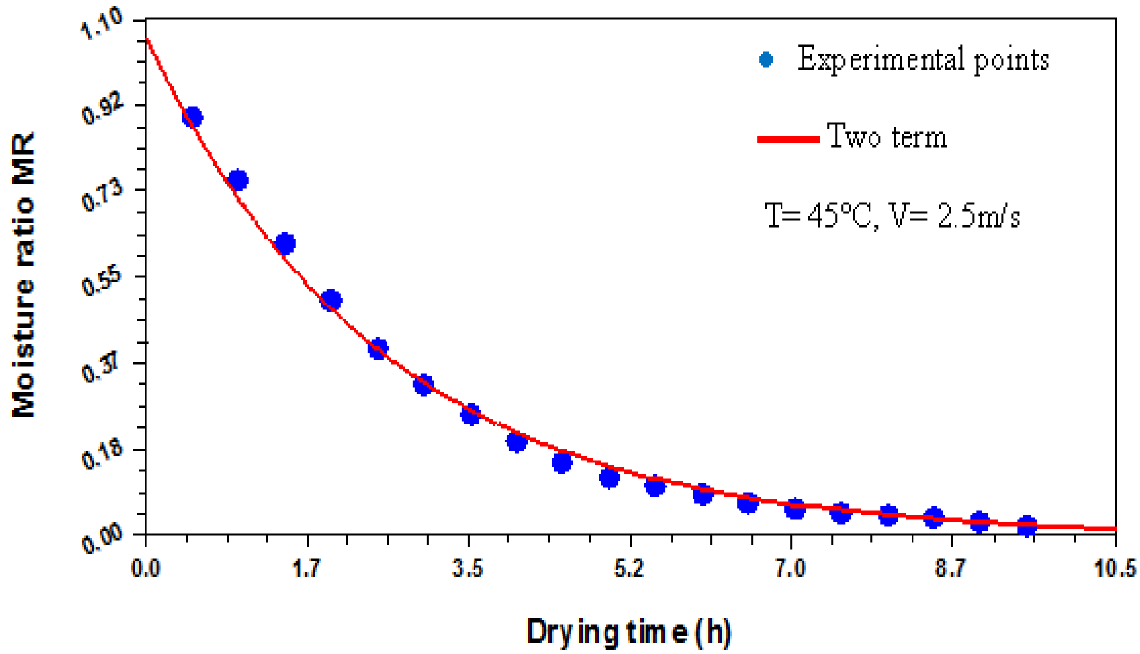

Experimental points
Logarithmic
T= 45°C, V= 2.5m/s
Moisture ratio MR
Drying time (h)
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.7
3.5
5.2
7.0
8.7
10.5

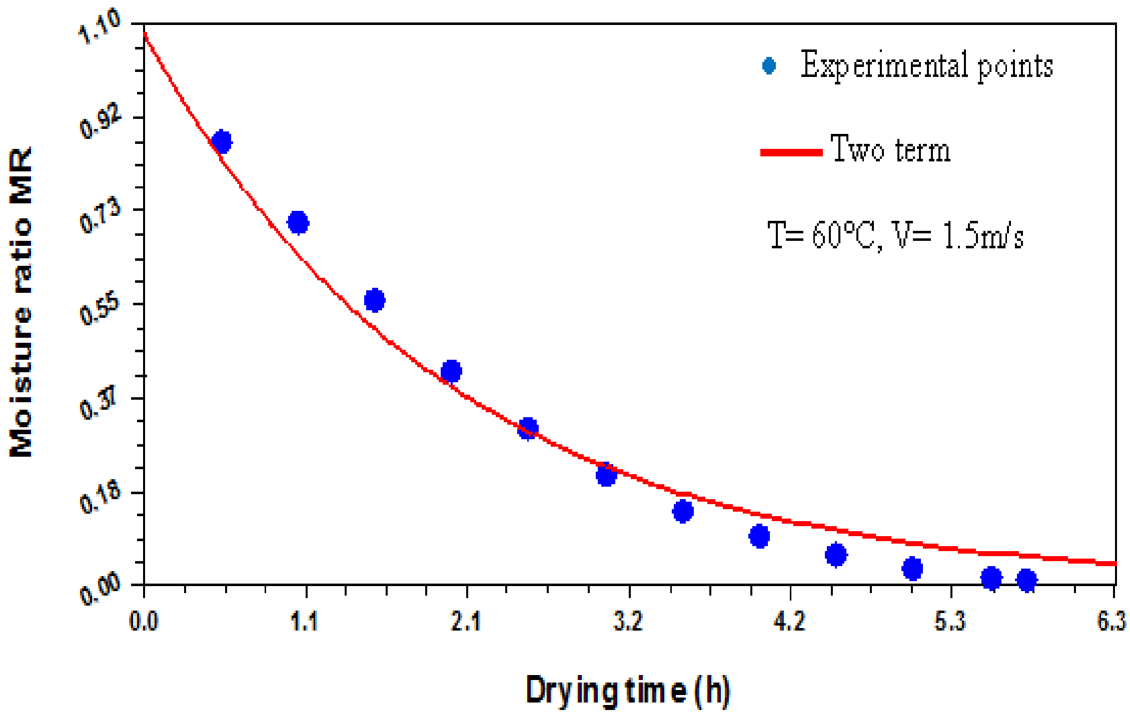

Experimental points
Logarithmc
T= 60°C, V= 1.5m/s
Moisture ratio MR
Drying time (h)
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.1
2.1
3.2
4.2
5.3
6.3

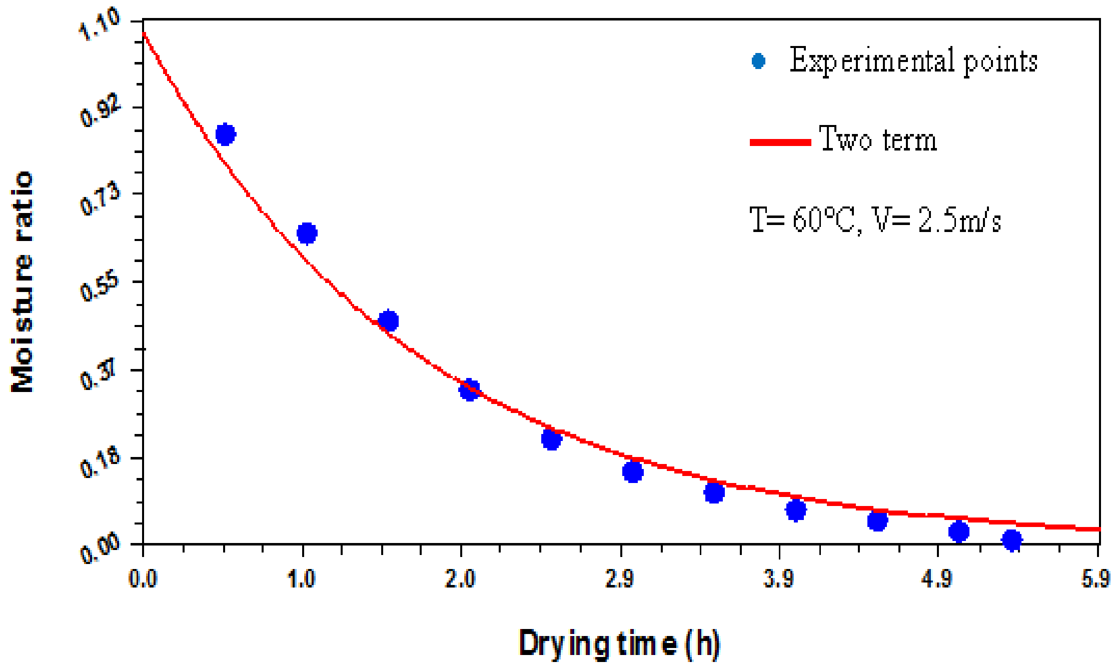


2.3. Two term model

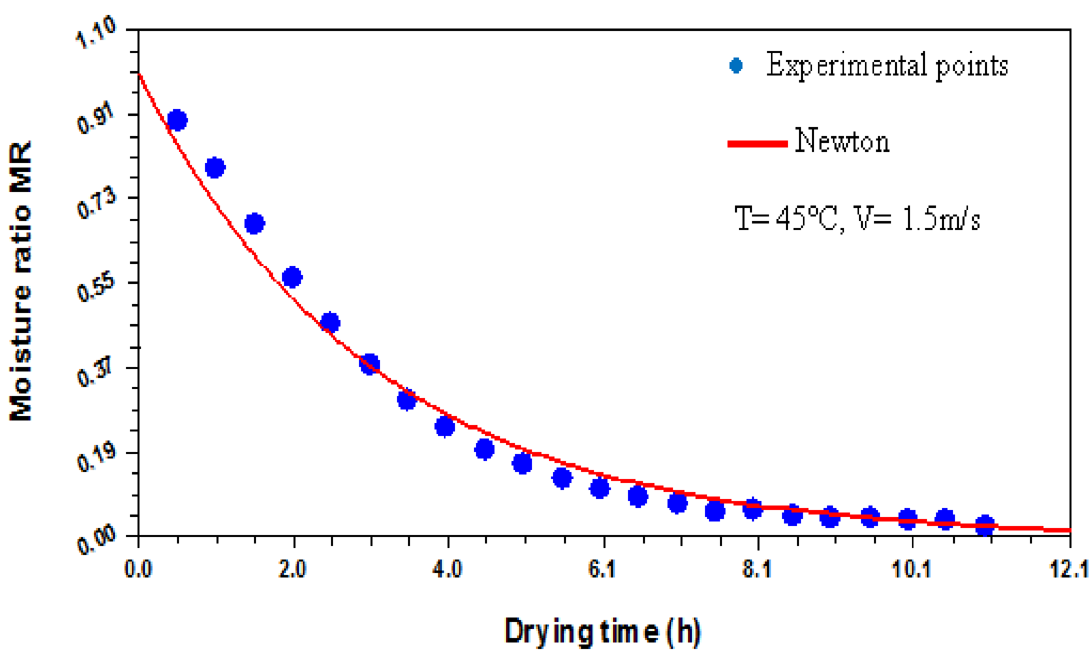


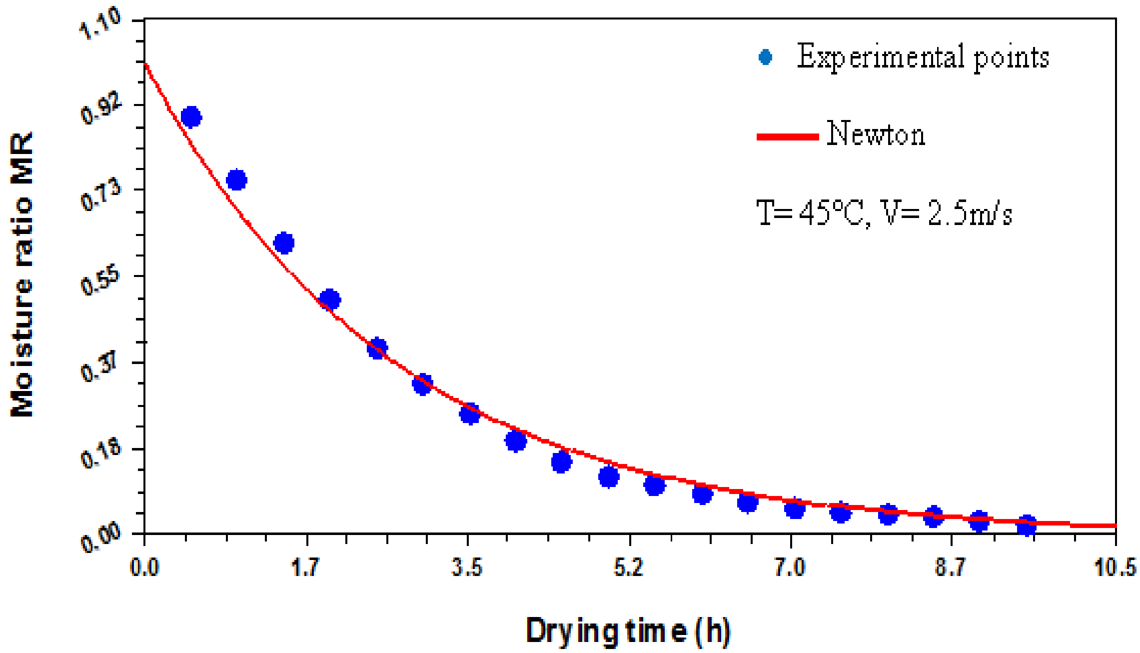

Moisture ratio MR
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.7
3.5
5.2
7.0
8.7
10.5
Drying time (h)
Experimental points
Two term
T= 45°C, V= 2.5m/s

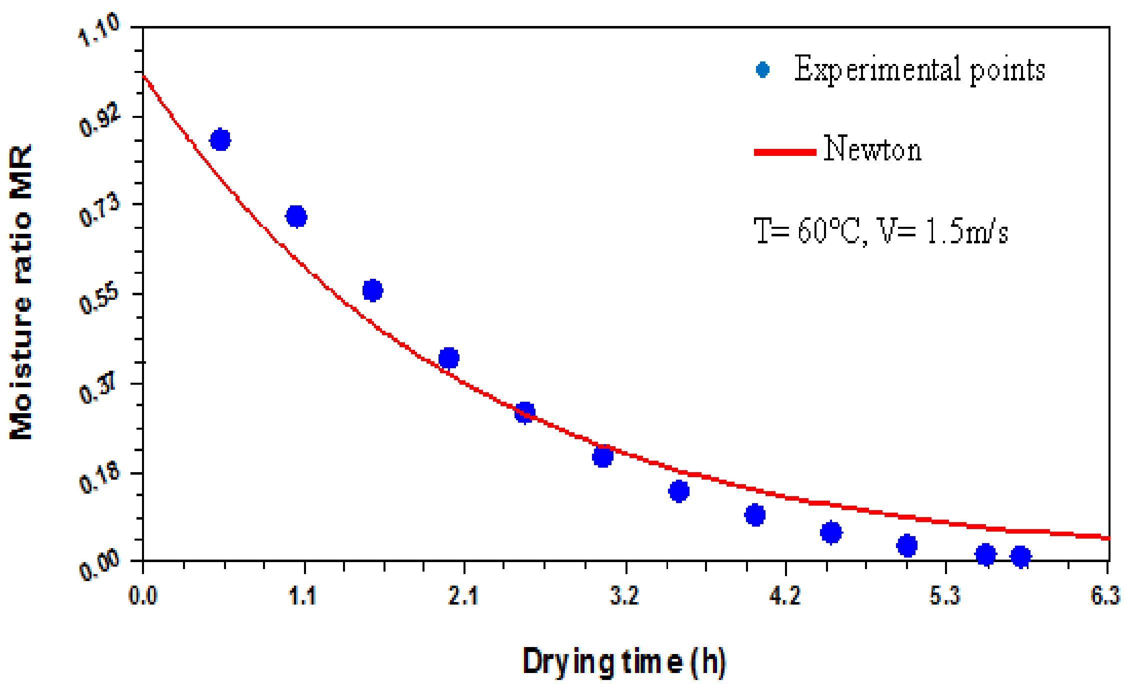

Moisture ratio MR
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.1
2.1
3.2
4.2
5.3
6.3
Drying time (h)
Experimental points
Two term
T= 60°C, V= 1.5m/s

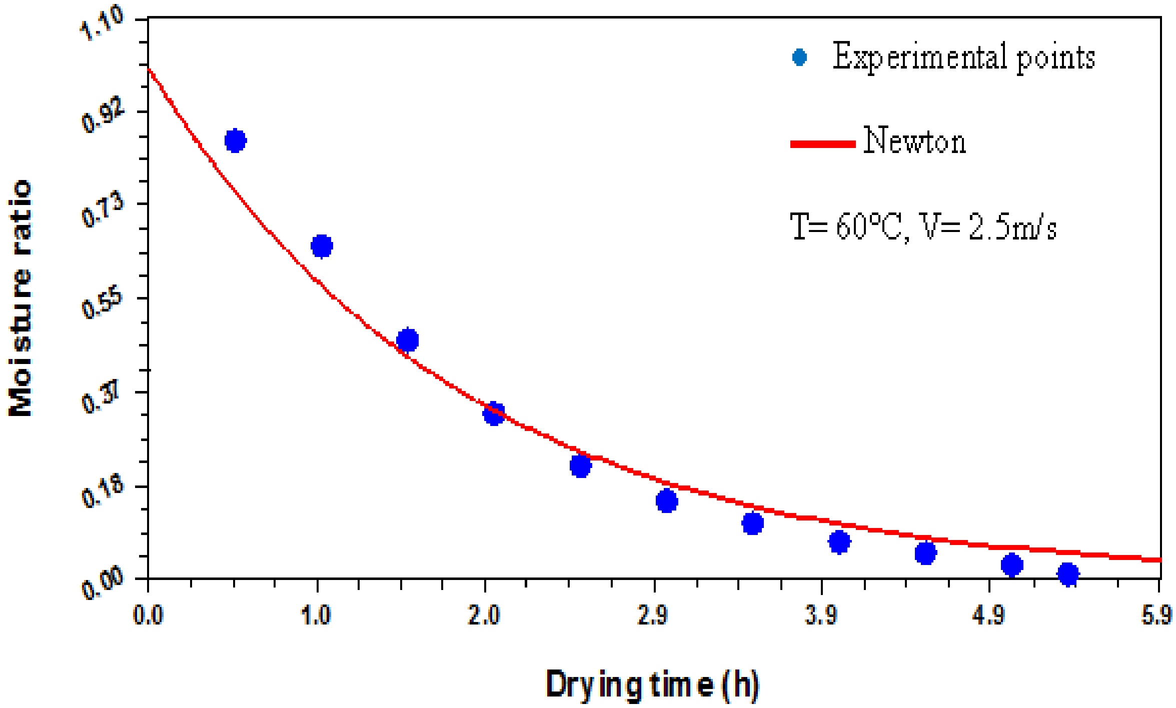


2.4. Newton model




Experimental points
Newton
T= 45°C, V= 2.5m/s
Moisture ratio MR
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.7
3.5
5.2
7.0
8.7
10.5
Drying time (h)


Experimental points
Newton
T= 60°C, V= 1.5m/s
Moisture ratio MR
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.1
2.1
3.2
4.2
5.3
6.3
Drying time (h)


Experimental points
Newton
T= 60°C, V= 2.5m/s
Moisture ratio
1.10
0.92
0.73
0.55
0.37
0.18
0.00
0.0
1.0
2.0
2.9
3.9
4.9
5.9
Drying time (h)

Laboratoire d'Energétique et des Transferts Thermique et Massique

Faculté des Sciences de Tunis
Département de Physique

Le 21/04/2018

ATTESTATION DE STAGE

Je soussigné, ***Mohamed Afif Elcafsi***, professeur au département de Physique de la Faculté des Sciences de Tunis et Directeur du Laboratoire d'Energétique et des Transferts Thermiques et Massiques LETTM, atteste que l'étudiant:

M. Abderrahim Boubekri, inscrit en deuxième année du mastère génie des procédés à la Faculté des sciences appliquées de l'Université Kasdi Merbah- Ouergla,

A effectué un stage de projet de fin d'études au Laboratoire d'Energétique et des Transferts Thermiques et Massiques LETTM au sein de l'équipe séchage des produits déformables sous la responsabilité scientifique de M. Soufien Azzouz.

Ce stage a été accomplie du 11/04/2018 jusqu'au 20/04/2018 et a porté sur le séchage de la pate des tomates à différentes conditions climatiques en utilisant la boucle de séchage de notre laboratoire LETTM.

Cette attestation est délivrée à l'intéressé, pour servir et valoir ce que de droit.

Le Directeur du L.E.T.T.M
Mohamed Afif EL CAFSI

Mohamed Afif EL CAFSI
Directeur du Laboratoire d'Energétique
et des Transferts Thermiques et Massiques

Faculté des Sciences de Tunis, Département de Physique – Campus Universitaire, 2092 Tunis-Tunisie

Abstract

This study was carried out with the objective of stabilizing, by drying means, the surplus of local tomato production. Obtaining an organic product in the form of tomato paste was then invested during the work of this memoir. The effect of two different drying conditions (air temperature and air velocity) on the drying behavior of a thin-layer tomato paste was experimentally investigated. Experimental drying kinetics were obtained at 45, 50 and 60°C: performed with airflow velocity of 1.5 and 2.5m/s. In order to optimize the drying processes (color quality and drying time), a $\mathbf{2^2}$ complete factorial design of four experiments with two levels of temperature (45 to 60°C) and air velocity (1.5 to 2.5 m/s) was used. The desirability index technique was used to predict the ideal drying conditions. At the best conditions of 45°C air temperature and 2.5 m/s air velocity, drying time was 5.32 hours and redness a* was 23.84. To fulfill the aim of this study, the attention was paid to mathematical modeling of experimental thin layer drying kinetics. PAGE model was the best fitted among five different investigated models.

Key words: tomato- drying- optimization- experimental design- modeling.

Résumé

Cette étude a été réalisée dans le but de valoriser, par des moyens de séchage, l'excédent de production loacle en tomates. L'obtention d'un produit biologique sous la forme de pâte de tomate a été alors investie au cours des travaux de ce mémoire. L'effet de deux différentes conditions de séchage (température et vitesse de l'air) sur le comportement de séchage d'une pâte de tomate en couche mince a été expérimentalement étudié. Les cinétiques expérimentales de séchage ont été obtenues à 45, 50 et 60°C; effectuées avec une vitesse de circulation d'air de 1,5 et 2,5 m/s. Afin d'optimiser les processus de séchage (qualité de couleur et temps de séchage), on a utilisé un plan factoriel complet $\mathbf{2^2}$ de quatre expériences avec deux niveaux de température (45 à 60°C) et une vitesse de l'air (1,5 à 2,5 m/s). La technique de l'indice de désirabilité a été utilisée pour prédire les conditions de séchage idéales. Dans les meilleures conditions de température de l'air à 45°C et de vitesse de l'air de 2,5 m/s, le temps de séchage était de 5,32 min et la rougeur a* était de 23,84. Enfin pour atteindre l'objectif de cette étude, l'attention a été portée sur la modélisation mathématique de la cinétique expérimentale de séchage en couches minces. Le modèle de PAGE était le mieux adapté parmi cinq différents modèles étudiés.

Mots clés : tomate- séchage- optimisation- plans d'expérience- modélisation.

ملخص:

أجريت هذه الدراسة بهدف تثمين فائض إنتاج الطماطم المحلي عن طريق تحويله الى منتج عضوي في شكل معجون الطماطم باستعمال المجفف الهوائي. تم اختبار تأثير اثنين من عناصر التجفيف المختلفة (درجة حرارة الهواء وسرعة الهواء) على سلوك تجفيف طبقة رفيعة من معجون الطماطم. تم الحصول على حركية التجفيف التجريبية في درجات حرارة 45، 50 و60 درجة مئوية. مع سرعتي تدفق هواء 1.5 و2.5 متر/ ثانية. من أجل تحسين عمليات التجفيف (جودة اللون ووقت التجفيف)، تم استخدام تصميم 2^2 عامل متكامل من أربع تجارب مع مستويين من درجة الحرارة (45 إلى 60 درجة مئوية) وسرعة الهواء (1.5 إلى 2.5 متر / ثانية). تم استخدام تقنية مؤشر الرغبة للتنبؤ بظروف التجفيف المثالية. في أفضل ظروف درجة حرارة الهواء 45 درجة مئوية وسرعة الهواء 2.5 متر/ ثانية، كان وقت التجفيف 5.32 ساعة وكان الاحمرار * a = 23.84. لتحقيق الهدف من هذه الدراسة، تم إيلاء الاهتمام للنمذجة الرياضية لحركية تجفيف الطبقة الرقيقة التجريبية. كان نموذج Page أفضل ما تم تركيبه بين خمسة نماذج بحث مختلفة.

الكلمات المفتاحية: الطماطم- التجفيف- المخطط التجريبي- النمذجة.